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THE INFLUENCE OF PHOSPHORUS FERTILIZATION ON WATER REQUIREMENTS OF BARLEY ON SHALLOW CHIN LOAM AT VAUXHALL

by

K. K. Krogman

University of Alberta

April, 1958

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THE INFLUENCE OF PHOSPHORUS FERTILIZATION ON WATER REQUIREMENTS OF BARLEY ON SHALLOW CHIN LOAM AT VAUXHALL

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ABSTRACT

A study of the water requirements of barley as influenced by phosphate fertilizer supply was conducted as a field plot experiment, and as a greenhouse experiment using the same soil. A minor study was also made of some of the methods of calculating potential evapotranspiration from observed meteorological data. The plot and the greenhouse experiment each employed four levels of soil moisture supply and four levels of phosphate fertilization in all combinations.

It was found that levels of soil moisture supply influenced yields, evapotranspiration and efficiency of water use to a greater extent than did levels of phosphate fertilization. In the field experiment, the higher soil moisture levels resulted in increased efficiency of water use, but in the greenhouse the higher moisture levels decreased the efficiency of water use. Increased phosphorus supply did not significantly influence the yields or the efficiency of water use in the field plots, but did significantly increase the yields and the efficiency of water use in the greenhouse. The lack of yield and efficiency of water use responses in the field plots was probably due to improper placement of the fertilizer and the influence of extraneous variables in the experiment.

Four methods of calculating potential evapotranspiration from meteorological data were compared with the consumptive use for maximum yields in the plot experiment. It was found that the conversion of the black Bellani plate evaporation to inches of evapotranspiration gave the best estimate of the actual value. The relationship between Bellani plate evaporation and evapotranspiration in the field did not hold under greenhouse conditions.

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THE INFLUENCE OF PHOSPHORUS FERTILIZATION ON WATER REQUIREMENTS OF BARLEY ON SHALLOW CHIN LOAM AT VAUXHALL

INTRODUCTION

A knowledge of the factors which affect the amount of water required for crop growth is important in semi-arid regions where as much of the soil moisture as possible must be conserved, and where stored moisture and rainfall must be used with greatest efficiency. Such knowledge is probably of more importance where irrigation is practised because it may affect estimates of the irrigation requirements of crops. In the construction and management of an irrigation project, consideration of seasonal requirements and times and magnitude of peak demands, is necessary for proper design and efficient operation of the project. In working out the hydrological balance and commercial use of the water from entire drainage basins, the hydrologist must know how much water is used by cultivated crops and by native vegetation. Whether on irrigated land or dry land, the amount of water required by crops is also of practical importance to the farmer.

All agronomic practices which may increase the efficiency of the use of water by crops are worthy of study. Such studies are important where rainfall is a limiting factor in crop production because ways may thereby be found to increase crop yields above the economic marginal level. They are also important where irrigation is practised, not only because they may lead to increased production but also decrease relative amounts of irrigation water required.

This thesis deals with an investigation of the use of water by barley on a southern Alberta soil. Two phases of this problem received attention:

1) An investigation of the influence of phosphorus fertilization

on the efficiency of water use, both in the field and in the greenhouse.

2) A test of the validity, under Alberta conditions, of some of the formulae which have been proposed for the determination from weather data of potential evapotranspiration.

To test adequately both the effect of fertilization on efficiency of water use, and also the validity of the formulae referred to, several different crops should have been included in the study, and the studies also should have been conducted over a period of several years. A more representative sample of average crop and climatic conditions would then have been observed, yielding information which would possibly be of wider applicability. However, in the limited time available for this investigation, only barley was tested and only one year's results are reported.

The 1957 crop season was comparatively dry, and was fortunately fairly representative of an average year as far as weather conditions in the Brown Soil Zone in Alberta are concerned. The conclusions reached in this study are therefore likely to be reliable, at least as applied to barley as an irrigated crop. Probably the general trends observed would also apply to other cereal crops grown on this particular soil type.

REVIEW OF LITERATURE

PHOSPHORUS IN THE SOIL

According to Pierre (38) the phosphorus in the soil may be classed under three broad categories as follows:

1) Inorganic forms, where phosphorus is combined with calcium, magnesium, iron, aluminum or clay minerals.

2) Organic compounds, consisting of plant and animal residues and the products of microbial synthesis.

3) Organic and inorganic compounds in living cells of plants and micro-organisms.

The inorganic phosphorus compounds in many soils, and particularly in the lower horizons, are in the form of fluorapatite, and this is the source of practically all soil phosphorus. The fluorapatite, by weathering processes is converted to secondary phosphorus compounds of varying solubility. The calcium phosphates form a series ranging from the relatively stable mono- and di-calcium phosphates to the slightly soluble hydroxy apatite and fluroapatite. The iron and aluminum phosphates may also vary widely in solubility. These exist largely as basic compounds which are very insoluble except under neutral or alkaline conditions. The clay lattice phosphorus is only very slightly available to plants, but clay adsorbed phosphorus is highly available. Phosphates of iron and aluminum tend to accumulate in acid soils, whereas calcium phosphates predominate in neutral or alkaline soils. Therefore, from the standpoint of phosphorus availability to plants, a soil pH of 6.5 to 7.0 is most desirable.

Hemwell (18) states that phosphorus is fixed in clay soils by a reaction involving aluminum. The aluminum originates from the dissociation of the clay lattice and from the exchange complex. The resultant aluminum phosphate is highly insoluble. The rate of fixation depends on the rate at which the clay replenishes the solution with

aluminum ions. The reaction is slow with the lattice-dissociated aluminum, but may be rapid with the aluminum from the exchange complex.

Olsen and Fried (35) point out that the total phosphorus in the soil is present in compounds which are not available to the crop in a single growing season. The phosphorus which is available for plant use originates from the release of the unavailable soil phosphorus or from phosphate fertilizers. Usually, available phosphorus is about one per cent of the total soil phosphorus, although this relationship varies widely. They also discuss the role of soil microflora in relation to the availability of phosphorus to the crop. They point out that when high energy materials such as crop residues or manure are added to the soil, the available soil phosphorus may be bound up in organic compounds within the bodies of a large population of micro-organisms. In this way temporary deficiencies of phosphorus may develop in much the same way as nitrogen deficiencies develop under similar conditions.

Data given in some of the Alberta and Saskatchewan soil survey reports (5, 31, 67, 68, 69) indicate that the total phosphorus content of the various horizons, down to and including the C horizon, of the soils of southern Saskatchewan and of central and southern Alberta, is from about 0.04 to 0.07 per cent. There appeared to be little regular variation in phosphorus content with depth in the soil, although in some isolated soil types, the content was greater in the "A" horizon than in the other soil horizons. Variations in phosphorus content also appears to be as great within districts as it is between districts.

The authors of Diagnostic Techniques for Soils and Crops (23) state that the total phosphorus content of many mineral soils is about 0.05 per cent. This would be about 1000 pounds of phosphorus per acre furrow slice. They also point out that the total phosphorus content of a soil is not useful in assessing the phosphorus fertilizer needs of a soil. This fact has been recognized by many workers in attempting to devise chemical soil

tests for determining phosphorus fertilizer requirements. Many tests have been used or proposed, but all of them are empirical as far as determining the available soil phosphorus fraction is concerned. The usefulness of these chemical tests has been based on the degree of correlation of the test results with field and greenhouse responses to phosphate fertilization.

The Soil Test Work Group (52) has given a summary of the sampling procedures and test methods used by various laboratories in the United States. This synopsis indicates that in fifty-one laboratories, some twenty-four extractants are being used. These extractants may be broadly classified as follows: 1) distilled water, 2) carbonated water, 3) dilute organic or inorganic acids, 4) dilute alkaline solutions, and 5) highly buffered neutral or acid solutions.

Recent reports would indicate that the dilute acid or alkali solutions, and the highly buffered acidic salt solutions have given better results than the other extractants, in the determination of so called available phosphorus. Olsen et al (34) proposed the use of 0.5 M $NaHCO_3$ at pH 8.5. They found that the calcium phosphates were increased in solubility by the lowering of the calcium ion activity in the solution, and that about one-half of the adsorbed phosphorus was extracted in their proposed extracting solution. Secondary precipitation reactions were claimed to be minimized. Their proposed method gave the highest correlation with "A" values, when compared with other methods.

"A" values, used in reference to soil fertility, are an expression of the amount of available nutrient in the soil in terms of a standard source of the nutrient. The proportion of the nutrient taken up by the plant from the standard source is determined either by chemical analysis of plant material from experiments where a series of rates of the standard fertilizer are applied, or by radioactive tracer techniques. A formula, developed by

Fried and Dean (12), and Dean (10), who developed the method, is then applied to calculate the "A" value.

Miller and Axley (28) proposed 0.03 N $H_2 SO_4$ plus 0.3N NH_4F as an extractant for phosphorus test work. This extractant was compared with several others in testing the soils used in a greenhouse experiment which included five levels of phosphate fertilization on seventeen Maryland soils. When all soils used in the investigation were considered, the results using their proposed extractant showed the closest relationship with crop responses to phosphorus fertilization.

Moller and Mogensen (32) used an ion exchanger zeolite for determining available soil phosphorus. The object in using this material was to eliminate the interference of the organic and inorganic acids, which are usually used for extraction, with the chemical properties of the soil colloids. The method was also considered to imitate the processes assumed to take place between soil colloids, the adsorbed cations, and the precipitated phosphates of the di- and tri-valent metals and of calcium. The method consisted of extraction of ten grams of soil with ten grams of sodium zeolite and 250 ml. of water. The phosphate content of the extract was determined colorimetrically and results were expressed as mg. of phosphorus per liter of extract. They considered soils to be phosphorus deficient if this value was less than 4; low, if between 4 and 8; usually not deficient if between 8 and 12; and rich in available phosphorus, if between 12 and 16.

The Soil Test Work group (53) reported a co-operative project covering seventy-four phosphorus experiments by fifty-five state and commercial testing laboratories in the United States and Canada. The results indicated that a dilute acid plus ammonium fluoride extractant for available phosphorus was least affected by such soil properties as pH. They indicate that the differences in correlation of test results with fertilizer responses, obtained by different laboratories using the

same extractants, emphasize the great influence of laboratory technique on soil test results.

PHOSPHORUS AS A NECESSARY ELEMENT OF PLANT NUTRITION

Phosphorus was among the first ten elements found to be essential for plant growth. Since its discovery as a plant nutrient, many other elements have been discovered as being essential for plant growth, but phosphorus, along with nitrogen and potassium, remains one of the most likely elements to be in limiting supply for plant nutrition.

Meyer and Anderson (26), in discussing the specific roles of essential plant nutrients, state that phosphorus is absorbed mainly as the $H_2PO_4^-$ion. This ion is not reduced in plant tissue, but is linked in organic compounds in a highly oxidized form. Phosphorus enters into the composition of phospholipids and nucleic acids which are the building blocks of the nucleoproteins and is therefore an important constituent of the nuclei of plant cells. A large proportion of the phosphorus content of the plant is located in the seeds and fruit. In young growing plants a high proportion of the total plant phosphorus is located in meristematic tissue. When phosphorus supply is low, inorganic nitrogen compounds are rapidly absorbed and accumulated, and when high, the absorption of nitrogen compounds is depressed. Phosphorus fertilization may therefore alter the nitrogen balance of the plant, and when phosphorus supply is adequate or high, earlier maturation of the plant will occur than when it is low. Low phosphorus availability results in the accumulation of anthocyanin, giving the characteristic purpling of vegetative organs which is associated with phosphorus deficiency. Meyer and Anderson conclude their discussion of the role of phosphorus in plant nutrition by stating that phosphorus is readily redistributed in the plant in the form of phosphates.

Miller (27) shows that the amount of phosphorus in plants ranges from 0.2 to 0.8 per cent of the total weight of dry material. In mature plants the greater amount of this is in the seeds. He also points out that since phosphorus is important in the nucleus of the cell, nuclear division is inhibited by low phosphorus supply and hence meristematic activity is diminished. There is little or no evidence however, according to Miller, to indicate that phosphorus supply influences the proportions of roots to tops in ordinary crops.

PLANT UPTAKE OF SOIL AND FERTILIZER PHOSPHORUS

Mitchell (29), in reviewing fertilizer studies in Saskatchewan, using radioactive tracer techniques, states that the wheat plant obtains most of its phosphorus from the fertilizer in early stages of growth, and that the proportion taken from the soil increases rapidly after the crop is four weeks old. Most of the phosphorus in the above ground parts migrates to the head during maturation. Increasing rates of fertilization resulted in decreasing uptake of soil phosphorus. Under drought conditions, he found that the proportion of fertilizer phosphorus taken up by the plant was increased. Certain varieties of barley appeared to show greater response to phosphorus fertilization than others. In this respect, Montcalm barley indicated a greater response than did Titan barley. Similar differences were not shown between varieties of wheat or oats.

Rennie (42), in examining the results from thirty radioactive phosphorus fertilizer experiments in the field, found that the per cent phosphorus in grain was significantly reduced as nitrogen applications were increased, whereas phosphate fertilization had no effect. Soil type and climate caused greater variations in per cent phosphorus in grains than did fertilizer rates. The protein content of grain was unaffected by nitrogen or phosphorus fertilization, but also varied greatly as a result of climatic and soil variations. The per cent phosphorus in wheat forage

varied with stage of growth, being initially high and decreasing to a minimal value at the soft dough stage. Rennie found no statistically significant relationship between phosphorus content of grain and yield.

CROP RESPONSE TO PHOSPHORUS FERTILIZERS

Peterson et al.(37) reviewed 275 papers, bulletins and unpublished reports dealing with fertilizer trials and experiments concerning crop response to phosphorus fertilization. These reports covered fifteen western states in the U.S.A. from 1910 to 1949. These authors state that according to the literature reviewed, crops show extreme variability in phosphorus fertilizer response from field to field and from year to year. Alfalfa appeared to be the most responsive crop. Small grains responded fairly consistently on phosphorus deficient soils, except where yields were also limited by other factors. As a rule the reports indicated that variations in crop response to phosphorus fertilization were as great within soil types as between them. The review indicated that the protein content of alfalfa and grain may be increased by phosphorus fertilization.

In summarizing the results of 470 fertilizer trials on wheat, Peterson (op. cit.) found that 31 per cent of these trials gave an increased yield of 5 bushels per acre or more, and 74 per cent gave an increase of one bushel per acre or more. Of 270 trials dealing with alfalfa, 31 per cent gave an increase of one ton per acre or more, and 65 per cent gave an increase of 0.4 ton per acre or more. Of 173 sugar beet trials reported, phosphorus fertilization increased yields by more than 5 tons per acre in 11 per cent of the trials, and one ton or more per acre in 76 per cent of the trials. These data clearly indicate that phosphorus fertilization often increases yields of the major farm crops in the fifteen western states.

Mitchell (30) reported the results of phosphorus fertilizer trials on a wide range of Saskatchewan soils, using 11-48-0, 0-43-0, and 2-20-0 at four comparable rates of phosphorus. The test crop used was wheat,

grown on summerfallow. The 11-48-0 formulation gave the largest responses. There was no distinct difference in responses between the dark brown and the black soils, nor between calcareous and non calcareous soils. Greater responses tended to occur during cool moist seasons than in hot dry seasons. Mitchell found no effect of phosphorus fertilization on bushel weights or on protein content. The latter finding does not agree with that of Peterson et al. (op. cit.).

The Alberta Advisory Fertilizer Committee (14) in their bulletin for 1956 indicate that the average yield of barley without fertilization for the ten previous years in central Alberta was 27.1 bushels per acre. This yield was increased 8.5 bushels per acre by the application of 50 pounds per acre of ammonium phosphate, 11-48-0. Their recommendations range from 25 to 50 pounds per acre of 11-48-0 for small grains on non irrigated lands, all soil zones included. For irrigated lands, they recommend 100 to 150 pounds of ammonium phosphate sulphate, 16-20-0.

The effectiveness of phosphorus fertilization in increasing the yields of crops grown on phosphorus deficient soils, has been shown to be influenced by the placement of the fertilizer. Stanford and Nelson (56) in discussing a fertilizer placement experiment with corn, using radioactive tracer techniques, found that more of the fertilizer phosphorus was taken up by the crop if it was placed in a band at the level of the seed, than if above the seed near the soil surface, or three inches below the seed. Greatest increases in yield of total dry matter were also obtained with fertilizer placement at the seed level. Taylor and Slater (59) report that phosphorus does not move appreciably in soils, and is taken up from approximately the same depth at which it is applied. They conclude that under irrigated conditions, if phosphorus is applied near the soil surface, and if it is a limiting element, yield increases will be best promoted by frequent, light irrigations.

Stanberry et al.(55), in a phosphorus fertilizer and irrigation experiment dealing with alfalfa, found that after four years the downward movement of phosphorus from the fertilizer was confined to the 18 inch depth. They also obtained the best yield responses where frequent light irrigations were used. Light and frequent irrigations would promote greater root feeding in the shallow part of the root zone, and the alfalfa plants would then derive more benefit from the fertilizer phosphorus, than if infrequent, heavy irrigations were applied.

In an experiment reported by Sell and Olsen (51), the effect of topdressing with limestone and of supplementary watering on the downward penetration of surface applied phosphate fertilizers on pasture was investigated. They found that the depth of penetration depended primarily upon the rate of application of the fertilizer, but even at 320 pounds per acre of P_2O_5, penetration beyond the twelve inch depth was very little. Penetration of available phosphorus was increased by the application of lime, and also appeared to be increased where the plots received supplementary water.

THE USE OF WATER BY PLANTS AND CROPS

The general need of water by plants is discussed by Miller (27) as follows:

A. The Protoplasm. All protoplasm contains a large proportion of water. The younger and more actively growing the organism, the greater the proportion of water in the protoplasm of the cells of the organism.

B. Vacuoles of Cells. Water is required in the vacuole to maintain the turgor of the cell. This turgor is essential for cell growth and for maintaining the form and erectness of plants.

C. Translocation of Materials. Plant foods and other materials within plants are translocated from one part of the plant to another in aqueous solution, therefore water is needed for this process.

D. Chemical Combination. Water is an important constituent of many of the organic compounds which are formed in plants. The amount of water used in such chemical combination is small when compared to that which is lost by transpiration.

E. Replacement. The water which is continually being lost by transpiration and sometimes by guttation, must be replaced by water taken from the soil.

Thorne and Peterson (60) refer to three terms which are synonymous and are used in connection with the amount of water required by various crops. These terms are "evapotranspiration ratio", "Water requirement" and "water cost of dry matter". These all refer to the units of water required by the plant to produce unit dry plant material, exclusive of the roots. Russell(47) points out that Lawes, in 1850, first investigated the water requirements of certain crops, and found that wheat, oats, barley, clover, beans and peas used from 200 to 270 pounds of water to produce one pound of total dry plant material. Briggs and Shantz (7), in 1913, published the results of experiments conducted in Colorado in 1911, wherein the water requirements of many crops were investigated. They found a wide range in the water requirements of different crops, with generally higher values than those of Lawes. Russell(op. cit.) concludes that, on the basis of the work of Briggs and Shantz, plants do not have unique water requirements but are influenced in this respect largely by prevailing meteorological conditions and soil moisture supply.

Thom and Holtz (64) reported the results of an intensive study of several factors which affect the water requirements of plants. These factors included the kind of crop, the concentration of the nutrient solution, the influence of supply of individual plant food elements, summer fallowing, concentration of alkali salts, previous crop, variety of crop, stage of plant growth, and soil moisture supply. The average water requirement for

six cereal crops was 312 pounds of water per pound of dry matter produced, and for four legumes, 429 pounds of water per pound of dry matter. Wheat, oats, corn and peas showed an increase in water requirement from early stages of growth up to the beginning of ripening, and then a decline to maturity. Crops having the deepest rooting systems also had the highest water requirements. Plants with higher ash content had higher water requirements. As the concentration of the nutrient solution was increased from one of meagre concentration for nutrition of plants, to one of optimum concentration, there was an increase in the total dry matter produced, and a decrease in the amount of water required to produce unit dry matter. The water use - total dry matter ratio for wheat and beans was reduced 34 per cent and 19 per cent respectively, when grown on summerfallow, as compared to growth on previously cropped land. When nitrogen, phosphorus and potassium were each in limiting supply, the water requirement was increased. Differences in water requirement due to variety were small.

Water requirements of alfalfa as influenced by irrigation regime and nutrient level are discussed by Schofield (50). In his experiment large pots were used, with three levels of watering and two levels of fertility. Within limits, it was found that the quantity of hay produced was directly related to the amount of water used by the crop. Lack of water did not increase the efficiency of water use, and resulted in decreased yields. A higher nutritional level, however, did increase the efficiency of water use and produced increased yields.

Sprague and Graber (54) found an increase in total water used but a decrease in the water use - dry matter ratio with increased nitrogen fertilization of alfalfa and bluegrass grown under greenhouse conditions. Similar results were reported by Amberger (2) in that fertilization of grass grown in pots increased the absolute consumption of water but

decreased the relative consumption per unit of green material produced.

Stanberry et al. (55) investigated the effects of varying moisture and phosphate supply on the production of alfalfa hay in Arizona, using field plots. They used three moisture levels and ten phosphate fertilizer rates or frequencies of application. Tensiometers were used for irrigation control. They found that yields were greatly affected by both the moisture and fertilizer variables. The results indicated that the goal for irrigation and fertilization procedure under their conditions should be frequent, light irrigations, with 200 pounds of phosphate fertilizer applied initially, plus 100 pounds applied annually. Depth of alfalfa root activity decreased with decreasing soil moisture tension, and also with increasing phosphorus fertilizer application. Water used by the crop varied from 7.1 to 16.5 acre-inches per ton of hay per acre produced, with the high rates of irrigation and fertilization giving the best efficiency of water use.

Hanks and Tanner (17) also found less soil moisture used per unit of crop yield when soil fertility was high than when it was low. Comparing the efficiency of water use under conditions of high fertility with that under low fertility, oats was 1.74 times as efficient, corn 1.43 times as efficient, and alfalfa 1.34 times as efficient.

Powers and Lewis (39), in dealing with irrigation in the Willamette Valley of Oregon, state that under good field management the water cost of alfalfa hay in that area is about six acre-inches of water per ton. They state that all good field management practices which result in optimum conditions for plant growth, including physical condition of the soil, and plant nutrient supply, tend to decrease the amount of water required to produce unit yield of the crop.

Ferguson and Michalyna (11) found that wheat grown on previously cropped land in 1956 and 1957 in Manitoba required one-quarter to one-third

less water per bushel per acre yield when fertilized with an ammonium phosphate fertilizer at 160 pounds per acre.

WATER AS A LIMITING FACTOR IN CROP PRODUCTION IN WESTERN CANADA

Average annual precipitation and evaporation from a free water surface at some of the experiment stations in Alberta and Saskatchewan is given below, the data are taken from the progress report of the Division of Field Husbandry, Soils and Engineering, Experimental Farms Service (44).

	Precipitation (inches)		Evaporation (inches)	
Station	Year Period	Ave. Annual	Year Period	Ave. Annual
Lacombe	41	17.9	26	14.6
Lethbridge	47	16.0	27	23.8
Manyberries	20	11.1	20	31.0
Swift Current	63	14.4	27	29.3
Scott	37	13.7		
Regina	63	14.7		
Indian Head	52	17.6		
Melfort	9	15.1		

These data clearly indicate that the driest districts of Southern Alberta and Saskatchewan are in the interprovincial border area close to the international boundary. Greater average annual precipitation occurs to the west, the north and the east of this generally dry district. Average annual evaporation tends to be high where rainfall is low, thereby aggravating the limitation of moisture for crop production.

Bowser and Mc Calla (6), in discussing the climate of the Brown Soil Zone state that lack of moisture is the most important factor in affecting crop production in that zone. They state that the average annual precipitation may vary from 6 to 26 inches and that approximately one-half

of the years may be classed as drought years. They point out, however, that nearly 80 per cent of the annual rainfall occurs during the previous fall, and during the growing season. The fact that June rainfall usually exceeds the precipitation for any other month of the year, enables crops to make efficient use of the limited annual precipitation.

Sanderson (49) has summarized the rainfall patterns for Canada. This writer also calculated the amounts by which the average annual rainfall is less than the annual evapotranspiration would be if the soil moisture was always in full supply for plant growth. This evapotranspiration estimate was worked out by a method developed by Thornthwaite (referred to later). The map showing these deficiencies for different areas in Canada shows the average annual deficiency is over two inches. The annual deficit is more than six inches in the southern prairies, and for the driest parts of Alberta and Saskatchewan, is over ten inches.

Hopkins (20), working with data from the central and southern districts of Alberta and Saskatchewan, found a significant correlation between the yield of wheat and the amount and distribution of rainfall. The influence of additional increments of rainfall at certain times was found to be dependent upon soil conditions. For example, if the soil fertility is high, late rains may cause lodging of the crop, with consequent reduction of yield. The maximum influence of rainfall upon yield increase occurs if it comes during June. He found only a moderate degree of correlation between the rainfall occurring in different districts during the year. The occurrence of drought over the whole area included in the study, during the same year, was infrequent. In a further study, Hopkins (21) found a positive correlation between the yield of wheat and pre-cropping season precipitation on summer fallowed and stubble plots in the southern districts. In the central districts, this relationship was not significant.

Staple and Lehane (58) analysed data for twelve years from seven substations in Saskatchewan. They found that for each additional inch of

water used by the crop there was an increase of 3.5 bushels per acre yield of wheat. The regression coefficient for rainfall on yield was 1.5 times that for soil stored moisture indicating that rainfall during the growing season is more important than stored moisture. In another paper (57) these writers report that summerfallowing conserves only an average of 21 per cent of the total precipitation occurring during the 21 month fallow period. Very little of the winter precipitation is stored in summerfallow, unless trash cover is present to retain the snow and prevent evaporation and soil drifting. Rains of less than 0.4 to 0.8 inches are ineffective in adding to summerfallow-stored moisture, unless they occur frequently. The practice of summerfallowing conserves moisture mainly because it controls weed growth.

The papers reviewed emphasize the importance of making maximum use of rainfall and stored soil moisture in the drier areas of western Canada. All soil management practices,including fertility, which may influence the efficiency of use of this moisture, deserve close attention.

CONTROL OF MOISTURE SUPPLY BY IRRIGATION

Both Baver (3), and Thorne and Peterson (6) give full discussions on past and present methods of determining when and how much to irrigate. Both of these authors state that visual examination of the crop is one of the oldest and most used methods for scheduling irrigations. Usually a temporary wilting of the leaves during the day indicates that soil moisture reserves are fairly well depleted and that irrigation is necessary. A darkening of the leaves of some crops may also indicate the need for watering. Thorne and Peterson point out, however, that repeated or prolonged wilting should not be allowed to take place, if damage by drought is to be avoided. They indicate that in most plants, photosynthesis has been shown to be reduced in the leaves if they are reduced in moisture content, although visible wilting may be evident at different degrees of soil dryness, in

different species of plants.

Various methods of measuring or estimating the moisture content of the soil for the purpose of irrigation control are discussed. Baver mentions that the direct sampling of the soil has been widely used, but this method is time consuming and has not been extensively used in practical field operations. Its use has been largely confined to experimental work and calibration of instruments employed in indirectly measuring soil moisture.

According to Thorne and Peterson (op. cit.), tensiometers have been used extensively where it is desired to maintain the soil moisture in plentiful supply. However, tensiometers cannot function at tensions greater than one atmosphere, and are therefore applicable over only the moister part of the range between wilting point and field capacity.

Various electrical resistance units have been used for measuring soil moisture and thus scheduling irrigations. These instruments employ the principle of increased electrical conductivity between two separated electrodes, with increased moistness of the material separating them. The material which separates the electrodes and which in some cases forms the body of the instrument or block, is usually gypsum, fibreglass or nylon. The block is embedded in the soil and changes in soil moisture content are reflected in changes in the moisture content of the material separating the electrodes. By the use of a Wheatstone bridge the electrical resistance between the electrodes is determined. By reference to a pre-determined calibration curve, the resistance reading can be converted to soil moisture percentage.

Thorne and Peterson (op. cit.) refer briefly to the use of neutron radiations for soil moisture determination, as proposed by Gardner and Kirkham. Estimation of soil moisture by this method is dependent upon the fact that hydrogen is the most effective element in slowing fast neutrons,

and that practically all of the hydrogen in the soil is in the soil water. Using a standard radiation source Garner and Kirkham (13) have found a good relationship between counts of low energy electrons and the water content of the soil between the oven dry condition and saturation.

A somewhat fresh approach in determining proper scheduling of irrigations is the use of a "moisture budget". A recent paper discussing this method is by Robertson and Holmes (46). A moisture budget implies a simple accounting system whereby records are kept of all of the water which enters the soil as precipitation and irrigation, and the water which is taken from the soil in evapotranspiration. Thus, if the moisture content of the root zone at the beginning of the growing season is known, the moisture content at any time during the growing season can be calculated. The unknown which must be determined is the periodical magnitude of the evapotranspiration. This is done by methods discussed later.

Thornthwaite and Mather (62) state that evapotranspiration depends on the following factors: 1) climate, 2) plant cover, 3) soil type and structure, 4) land management, and 5) supply of soil moisture. According to these writers, there is evidence which shows that if moisture conditions are optimum for plant growth, management and soil factors have little effect on transpiration. Water loss from the soil is therefore determined principally by climatic factors.

Penman, Blaney and Criddle, and Thornthwaite have all developed formulae designed to estimate the magnitude of evapotranspiration from meteorological data. The work of these men is discussed by Thorne and Peterson (60) as follows:

1) Penman, in 1948, found the transpiration from grass to be 0.6 times the evaporation from a free water surface during the winter months, and 0.8 times the evaporation during the summer months. He considered the ratio of evapotranspiration to evaporation from a free water surface to be

constant for all crops provided they cover the ground and are amply supplied with moisture.

2) Blaney and Criddle estimate evapotranspiration from mean monthly air temperatures and relative per cent of daytime hours. Their formula is $U = KF$

where U = evapotranspiration
K = an empirical coefficient
F = the sum of the factors affecting evapotranspiration for the growing season

or $F = \Sigma f$

where $f = \frac{tp}{100}$
t = mean monthly temperature in degrees Fahrenheit
p = per cent daytime hours of the year.

3) Thornthwaite estimates evapotranspiration by the equation

$$e = 1.6(10\ t/I\ )^a$$

where e = the monthly evapotranspiration in centimeters
t = mean monthly temperature in degrees centigrade
I = heat index, which equals the sum of the monthly heat index values, each of which equals $(t/5)^{1.514}$
a = an empirical coefficient that varies with I.

Penman (36) points out that evaporation is a physical process which is dependent upon two basic conditions: a source of energy for vaporization, and a means of removal of the vapor. According to him, the weather data needed to estimate evaporation includes the duration of sunshine, the humidity of the air, and the wind speed.

Blaney (4) uses the term consumptive use of water synonomously with evapotranspiration. He defined consumptive use as including the loss of water by evaporation from the soil surface plus the losses from interception by plant cover, plus plant transpiration. Criddle (9) points out that

consumptive use of water varies widely for perennial crops but not so widely for annuals. For example, consumptive use for alfalfa in Arizona is about 4.5 feet per year, whereas in higher northern valleys it is about 1.5 feet per year. Consumptive use for wheat is from 15 inches to 18 inches regardless of where it is grown.

Thornthwaite (61) and Thornthwaite and Mather (63) discuss the development of the Thornthwaite formula for the calculation of potential evapotranspiration on the basis of temperatures and daylight hours. The term, potential evapotranspiration, was introduced by Thornthwaite (op.cit.) as meaning the amount of evapotranspiration which would occur under given climatic conditions if the soil cover by plants was complete, and soil moisture was in continuous full supply for plant growth. Both of the above mentioned references give full instructions for the use of the Thornthwaite formula,and include tables and nomograms as computing aids, without which the calculations would be complicated and laborious.

The Thornthwaite formula was tested by Sanderson (48) in Ontario. Grass was grown in a soil filled tank which was buried so that the level of the soil in the tank was at ground level. The same crop was seeded on the surrounding area to overcome an isolation effect upon the crop in the tank. The tank was connected by piping to a water supply in such a manner that the rate of water use by the grass growing in the tank could be measured. Good correlation was obtained between evapotranspiration as measured by this method, and potential evapotranspiration as calculated by applying the Thornthwaite formula to weather data.

Robertson (45) lists the following evaporimeters which are in current use.

1) The four-foot evaporation tank.
2) The Summerland tank.
3) The black Bellani plate atmometer.
4) The white Bellani plate atmometer.
5) The Piche atmometer.

During 1953 Robertson (op. cit.) compared these five methods of measuring evaporation with each other in their response to the mean daily temperature, the average daily wind speed, the total solar radiation, and the average daily vapor pressure deficit of the atmosphere. He found that the black Bellani plate data showed the highest correlation with fluctuations in each of these meteorological factors. Since these meteorological factors are considered to exert major influences on evapotranspiration, he concluded that evaporation as determined by this instrument should be more closely related to evapotranspiration than the data obtained from any of the other evaporimeters.

Livingston (25) describes the Bellani plate in detail, and mentions that it was developed by Bellani about 130 years ago. The evaporating surface is a circular porous plate about 7.5 centimeters in diameter, which forms the flat surface of a near hemispheroidal vessel, with a cylindrical neck perpendicular to the evaporating surface and on the spheroid side of the vessel. The instrument is a single ceramic casting with all parts glazed except the evaporating surface. It is mounted in such a way that the evaporating surface is horizontal and uppermost, and is fully exposed to the evaporating conditions. A continuous column of water is maintained within the instrument which is connected by a suitable system of tubing to a water supply reservoir. Measurement of amounts of evaporation is accomplished by weighing the instrument and reservoir at desired intervals, or from graduations showing volume loss from the water supply. Evaporation, as determined by this instrument is usually expressed in cubic centimeters per unit of time.

In working out a moisture budget for scheduling irrigations, Robertson and Holmes (46) proposed that the cubic centimeters of water evaporated from the black Bellani plate can be converted to inches of

evapotranspiration by multiplation by the factor, 0.0034. This is based on "an average of several comparisons with free water evaporation, actual evapotranspiration measurements, and data based on irrigation experience".

The budget method of determining time of irrigation is discussed by Van Bavel and Wilson (66) in reporting the results of an experiment conducted in North Carolina. Mercury tensiometers were used for scheduling irrigations of tobacco in 1950 and 1951. The dates for the irrigations were also determined by the moisture budget method wherein evapotranspiration was estimated from weather data using the formula of Blaney and Criddle. The calculated dates varied from the actual dates for irrigation based on moisture tension, by more than one day in only one instance out of ten. These workers also calculated the average monthly potential evapotranspiration from weather data for the entire year using the methods of Penman, Blaney and Criddle, and Thornthwaite. These estimates were compared with evaporation rates from a free water surface. They concluded that, although the data obtained did not coincide, all of the methods may estimate latent evapotranspiration with sufficient accuracy for use in maintaining a practical moisture budget for irrigation control.

Pruitt and Jensen (41) compared the rates of consumption of water by four crops, with rates of evaporation from an evaporation tank and with evapotranspiration estimated by the Blaney and Criddle, and the Thornthwaite procedures. They found that where crops cover the soil, the evaporation tank data more closely estimated the actual water consumption rates than did the calculated evapotranspiration.

Pruitt, in a subsequent paper (40) discusses the mechanics of a convenient method of applying evapotranspiration estimates based on evaporation tank data, to the maintenance of a moisture budget for scheduling irrigations. The device described is simply a mechanical means of keeping an up to date score of the soil moisture by adding rainfall and irrigation

and subtracting estimated evapotranspiration. This "irrigation guide" was used with success at Prosser, Washington, during the 1954 growing season.

According to Halstead and Covey (16) the limitations in the equations which have been proposed for estimating evapotranspiration are due to the following sources of error:

1) Where general meterorological entities for an area are used in the formulae, these may not be valid because of local variations in microclimate.

2) Evaporation tends to lower the mean temperature, and so the relationship between temperature and evapotranspiration is complicated and is subject to change.

3) Where a formula uses wind speed as basic data in relation to vapor transfer, this speed must be taken at several heights, or be corrected by some measure of surface roughness which would take into account the height and nature of the crop.

4) Mean values of temperature and other meteorological factors are not accurate, and the accuracy of the formula becomes dependent upon the correlation between these data and the true instantaneous values.

Lemon _et_ _al_. (24) state that evapotranspiration depends not only on meteorological factors but also on soil and plant factors as well. Soil moisture tensions must be taken into consideration. The plant itself, directly or indirectly exerts variable restrictions on the system of water transfer from the soil to eventual loss to the atmosphere. To quote these authors, "The soil, the plant and the atmosphere form a single system for the transfer of water. Such terms as transpiration, translocation, adsorption and availability of soil moisture all refer simply to various aspects of this transfer. More attention has been given to the individual elements of this system than to the system as a whole. It is the result of the interaction of the three components of the system, not their absolute values, which influences the growth and behavior of plants and thus warrants intensive study."

OBJECT AND HYPOTHESIS

The object of this study was to investigate the water requirements of barley on a southern Alberta soil, dealing with the following phases:

1) A study of the influence of phosphorus fertilization on the use of water by this crop, using a field plot experiment conducted at the Irrigation Substation, Vauxhall, during the summer of 1957, and a greenhouse experiment using the same soil at the University of Alberta.

2) By means of the formulae proposed by workers elsewhere, calculation from weather data of the theoretical evapotranspiration, and comparison of these values with the consumptive use of water as actually measured for maximum yields of the crop in the plot experiment.

Increased efficiency of water use by various crops has been observed where the application of commercial fertilizers has improved soil fertility (2, 17, 50, 54, 55, 64). It was assumed, therefore, in this experiment that increasing rates of phosphorus fertilization would decrease the water required by barley in producing unit dry weight of total plant material. The second phase of the study was undertaken to test the applicability of the formulae for determining potential evapotranspiration from weather data, to southern Alberta conditions.

MATERIALS AND METHODS

SOIL

The soil used in the field plot experiment was classed as Shallow Chin fine sandy loam to loam (22). The pH and electrical conductivity data for two locations, one on the east and one on the west side of the plot area, at various depths down to the fourth foot, are presented in Table I.

Table I. pH and electrical conductivity in mmhos/cm. (saturation extract) of the soil in the plot experiment.

	West		East	
Depth	pH	Ec.	pH	Ec.
0 - 6 ins.	7.03	1.72	7.04	1.19
6 - 12 "	7.80	1.67	6.90	3.19
12 - 24 "	8.25	3.81	7.74	0.55
24 - 36 "	7.67	1.82	8.05	0.52
36 - 48 "	7.46	1.13	8.51	1.30

The highest salt concentrations occurred in the 12 to 24 inch depth on the west side of the plot area, and in the 6 to 12 inch depth on the east side. However, these data indicate that the salt content of the soil was well below the critical level for many crops, particularly for barley (43). The pH of the soil averaged slightly above 7, and therefore, alkaline-earth carbonates were not likely to be present (43).

The moisture holding characteristics of the soils on the substation, including the Shallow Chin soil, are determined at Vauxhall as routine analyses. According to these data (22), the average apparent specific gravity of the soils to the three-foot depth on the plots is 1.50. The moisture content at field capacity is 25 per cent and at wilting point, 12 per cent. On the basis of these data, the total available water at field capacity for the top three feet of soil was calculated to be 7.0 inches. This estimate of available water holding capacity was used in calculating the amounts of irrigation to be applied to the plots. The irrigation procedure is discussed in the details of the methods used in the plot experiment.

The soil used in the greenhouse study was surface soil taken from several locations immediately adjacent to the east and north sides of the plot area. It was passed through a builder's gravel screen to remove stones and coarse trash, and was then thoroughly mixed. There was no

notable difference between this soil and the surface soil on the plot area.

Mechanical analysis of the greenhouse soil was done by the modified pipette method as outlined by Toogood and Peters (65). The sand silt and clay fractions were found to be 45, 37, and 18 per cent respectively. It was therefore classed as loam. The pressure plate method of determining the 15 atmosphere tension moisture percentage, as described in Handbook 60 (43) was used to determine the wilting point. The field capacity was determined by the cylinder method. In this method a column of soil contained in a cylinder with a porous bottom, is moistened and then allowed to drain for 48 hours. A sample is then removed from the two to four inch depth, and the sample is then oven dried for per cent moisture determination.

These determinations indicated that the moisture content of the greenhouse soil at field capacity was 25 per cent, and at wilting point was 8 per cent. As with the plot experiment, these moisture characteristics were used in calculating the time and amount of watering in the greenhouse. The soil on the plots was relatively sandy near the surface, with increased clay content at lower depths. Since plow depth soil only was used in the greenhouse, this accounts for the discrepancy between the wilting points of the greenhouse soil, and the average wilting point for the three-foot depth on the plots.

The "available" phosphorus content of the greenhouse soil was determined by extraction with 0.03 N H_2SO_4 plus 0.03 N NH_4F as outlined by Miller and Axley (28). For phosphorus determination in the extract, the ammonium-vanadate method of colorimetric determination was used. (See appendix A).

PLOT EXPERIMENT

The plan of the plot experiment is shown in figure I. Four levels of phosphate fertilization were combined with four levels of irrigation,

Figure I Field Plot Plan

North

E

W_3P_1	W_1P_1	W_0P_0	W_1P_2
W_0P_3	W_3P_0	W_3P_2	W_2P_0
W_1P_0	W_2P_3	W_1P_3	W_0P_1
W_2P_2	W_0P_2	W_2P_1	W_3P_3

C

W_1P_0	W_2P_0	W_3P_3	W_2P_1
W_2P_3	W_0P_2	W_1P_1	W_1P_2
W_0P_1	W_1P_3	W_2P_2	W_0P_3
W_3P_2	W_3P_1	W_0P_0	W_3P_0

A

W_3P_1	W_2P_2	W_0P_3	W_1P_0
W_3P_0	W_2P_1	W_0P_1	W_1P_2
W_3P_2	W_2P_0	W_0P_0	W_1P_3
W_3P_3	W_2P_3	W_0P_2	W_1P_1

D

W_1P_3	W_0P_0	W_3P_3	W_1P_1
W_0P_1	W_1P_2	W_1P_1	W_2P_0
W_2P_2	W_2P_3	W_1P_0	W_3P_2
W_3P_0	W_3P_1	W_0P_2	W_0P_3

B

W_0P_2	W_1P_3	W_2P_1	W_0P_0
W_3P_2	W_3P_3	W_1P_1	W_1P_0
W_1P_2	W_0P_3	W_0P_1	W_3P_0
W_2P_2	W_2P_3	W_3P_1	W_2P_0

giving a total of 16 treatments, which were replicated five times. The design was such that it could be analysed as a standard 4 x 4 balanced lattice experiment.

The fertilizer treatments were as follows:

Po - no phosphate fertilizer.

P_1 - phosphate fertilizer at 40 pounds per acre P_2O_5.

P_2 - phosphate fertilizer at 80 pounds per acre P_2O_5.

P_3 - phosphate fertilizer at 120 pounds per acre P_2O_5.

Ammonium phosphate (11-48-0) was used as the phosphate source, and all treatments were balanced with respect to nitrogen application by using ammonium nitrate (33.5-0-0) at suitable rates. A basal application of 40 pounds per acre of 33.5-0-0 was also drilled in with the barley seed; thus all plots received a total of 40.5 pounds per acre of nitrogen. The phosphate fertilizer treatments on the individual plots had to be applied by hand as a top dressing, because a machine suitable for seeding individual small plots at varying rates of fertilization, was not available. After spreading the fertilizer, the plots were raked with a hand rake. All of the phosphorus treatments were applied in two equal applications, within two weeks after seeding.

The four irrigation levels were as follows:

W_o - no irrigation

W_1 - irrigation when the moisture content of the root zone was depleted to 25 per cent of the available water capacity, in quantity to moisten the soil to field capacity.

W_2 - irrigate when the moisture content of the root zone was reduced to 50 per cent of the available water capacity, in quantity to moisten the soil to field capacity.

W_3 - irrigate when the moisture content of the root zone was reduced to 75 per cent of the available water capacity,

in quantity to moisten the soil to field capacity.

Based on the above criteria, and taking into consideration the moisture holding characteristics of the soil, the amount of water to be applied at each irrigation was calculated to be 5.25 inches for treatment W_1, 3.50 inches for treatment W_2, and 1.75 inches for treatment W_3.

Times of irrigation were determined by maintaining a soil moisture budget during the growing seasons. Robertson's proposed factor, 0.0034 (46), was used to convert c.c.'s of evaporation from the black Bellani plate evaporimeter, to inches of potential evapotranspiration. Since the plots under treatment W_3 were to be irrigated more frequently than the others, and since the soil moisture was to be maintained at the optimum or above optimum level for plant growth, the rate of water use for these plots was estimated by using the potential evapotranspiration as calculated. Plots under irrigation treatment W_2 were expected to use water at a lower rate because of less frequent irrigation, and lower average soil moisture content for the season. Therefore, for plots under treatment W_2, rate of water use was estimated by multiplication of the potential evapotranspiration by the factor 0.8. Since irrigation treatment W_1 was expected to use water at a still lower rate, the potential evaporation was multiplied by 0.6 to estimate rate of use for these plots. These factors 0.8 and 0.6 were based on existing knowledge of the crop use of water as determined in former experiments (22) at the Vauxhall substation.

The irrigation water was conveyed to the plots in a closed pipe system. Measurement of the amount of water delivered to each plot was accomplished by using the co-ordinate method of measuring pipe flow. This method of measuring water is discussed by Thorne and Peterson (60). It is based on the principle of the rate of flow from a horizontal pipe being related to the trajectory in vertical and horizontal distances, of the stream issuing from the pipe. The rate of application of water on each plot at each time of irrigation, was 5 minutes per inch depth of water over the

plot area.

Actually, treatment W_1 was given 5.2 inches of water at each irrigation, treatment W_2, 3.4 inches and treatment W_3, 2.0 inches. Water application to treatment W_3 was adjusted upward to compensate for evaporation losses while the water was being applied. This was considered necessary because with frequent, light irrigations, a greater portion of the water would evaporate before entering the soil. The water was applied at the above mentioned rate and measurement was by means of timing. Since the rate of application was rather high, the amounts to be applied to treatments W_1 and W_2 were reduced to eliminate fractions of a minute in the length of time required to apply the desired water to each plot.

Individual plots were 7 feet by 13 feet, and were separated within replicates by a five-foot wide ditch installed with a field ditcher. This ditch served to isolate the plots one from another, and to provide a bank for retention of irrigation water on the plot. The replications were separated by a pathway which was five feet wide between the outer banks of the ditches surrounding each replication.

Before laying out the plots, the area was plowed, worked down and smoothed in mid-May. Montcalm barley was seeded on the area on May 22 at 2½ bushels per acre, using a field type seeder. After seeding, the plots were located on the area, and the plot separating ditches were constructed.

Since the soil moisture content was low in the spring, and since very little rainfall occurred during May, the entire plot area was irrigated by sprinkling on May 31, applying 3/4 inch of water. Because of delays in assembling the equipment necessary for individual plot irrigation, the plots were not irrigated during June. All plots except, treatment W_0, were irrigated to field capacity, according to the moisture budget, at the end of June. After this time the differential moisture treatments were maintained. Irrigations were discontinued on August 6, when the barley was in the soft to firm dough stage, depending on watering treatment. During the

season, treatments W_1 were irrigated twice, treatment W_2, three times and treatment W_3, six times.

The plots of irrigation treatment W_0, were ripe on August 12, of treatment W_1 on August 14, of treatment W_2 on August 20, and of treatment W_3 on August 21. Six drill rows, each nine feet in length were harvested from the centre of each plot, when the grain was ripe. The height of the crop on each plot was recorded. The plots were harvested by hand, and the barley plants were cut as close as possible to the soil surface. The harvested material was air dried, the total weight of grain plus straw recorded before threshing, and the weight of straw determined by subtracting the weight of the grain after threshing from the total harvested sample weight. Bushel weights of the grain were determined, and a sample of the grain and of the straw from each plot was prepared for chemical analysis by grinding in a Wiley Mill.

The soil was sampled in one-foot depths down to the third foot, at three locations on each plot, at seeding time, and at harvest time. These samples were used to determine the moisture content of the soil at these times. The oven drying method of moisture determination was used. The average moisture content for the three sampling locations on each plot was taken to represent the true moisture content of the soil for the particular time. The purpose of these moisture determinations was two-fold. They provided a basis for calculation of changes over the growing period of soil moisture conditions on each plot, and also the spring soil moisture determinations provided a starting point for the soil moisture budget.

The calculation of actual consumptive use of water for each plot for the growing season was based on changes in soil moisture content and on the amount of water received by the plot. The total irrigation plus precipitation, expressed in inches depth of water, was adjusted by adding or subtracting as necessary the changes in soil moisture, spring to fall, also expressed in inches. Since the season was dry and each plot was

enclosed by the bank of a ditch, loss of water by deep percolation was unlikely, and by surface runoff was impossible. The consumptive use of water, as determined by this method was therefore reasonably accurate.

THE GREENHOUSE EXPERIMENT

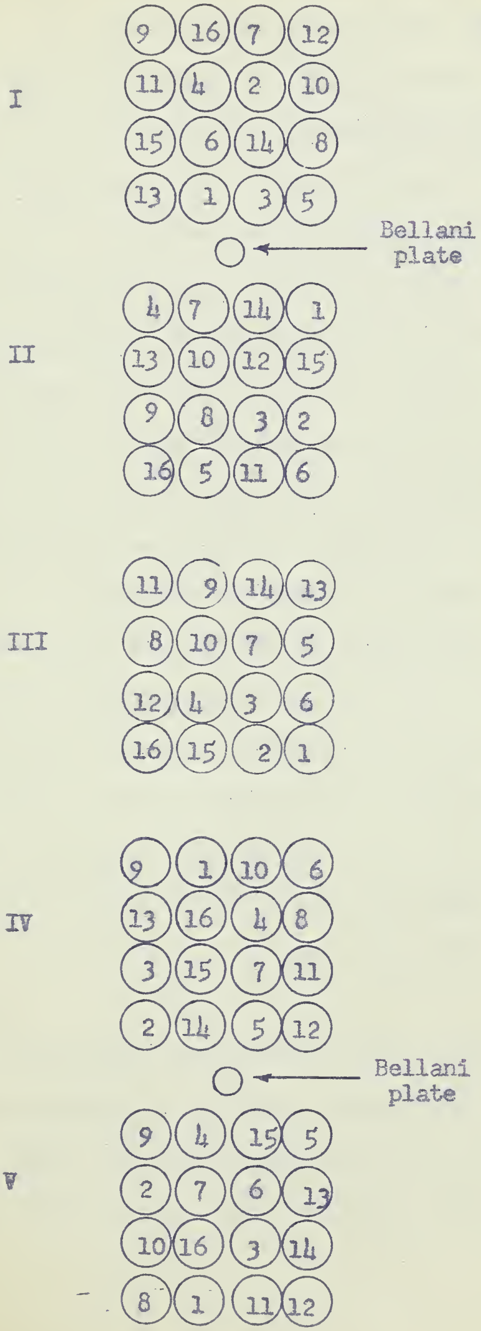
This was designed to parallel the plot experiment. It also included four levels of phosphate fertilization in all combinations with four levels of water supply to give 16 treatments, which were replicated five times. The experimental design was also a balanced lattice. The bench plan is shown in figure II. Glazed, one gallon crocks without drain-holes were used as pots, and 12.5 pounds of air dry soil was used in each crock. The soil was not diluted with sand, but was used as obtained from the field, except for screening and mixing as has already been described.

The rates of phosphorus fertilization were based on the surface area of the soil in each pot. The fertilizer treatments were as follows:

P_0 - no phosphate fertilizer
P_1 - 40 pounds per acre P_2O_5
P_2 - 80 pounds per acre P_2O_5
P_3 - 120 pounds per acre P_2O_5

Ammonium phosphate sulphate 16-20-0 was used as the phosphate source. All treatments received the equivalent of 108 pounds of nitrogen per acre. All other essential elements, including potassium were considered to be in ample supply for plant growth. The fertilizers were applied in a layer about one inch below the soil surface at the time of seeding. The ammonium phosphate (16-20-0) and ammonium sulfate (21-0-0) were used instead of 11-48-0 and 33.5-0-0 because larger quantities of these fertilizers would be required for each pot. Possibility of error in weighings thus would be reduced.

Figure II Greenhouse bench plan



I

9	16	7	12
11	4	2	10
15	6	14	8
13	1	3	5

II

4	7	14	1
13	10	12	15
9	8	3	2
16	5	11	6

III

11	9	14	13
8	10	7	5
12	4	3	6
16	15	2	1

IV

9	1	10	6
13	16	4	8
3	15	7	11
2	14	5	12

V

9	4	15	5
2	7	6	13
10	16	3	14
8	1	11	12

Number	Treatment
1	W_1P_0
2	W_1P_1
3	W_1P_2
4	W_1P_3
5	W_2P_0
6	W_2P_1
7	W_2P_2
8	W_2P_3
9	W_3P_0
10	W_3P_1
11	W_3P_2
12	W_3P_3
13	W_4P_0
14	W_4P_1
15	W_4P_2
16	W_4P_3

The watering treatments used in the greenhouse were as follows:

W_1 - water when the soil moisture content was reduced to the wilting point in quantity to bring up to field capacity.

W_2 - as above but water when the soil moisture was reduced to 25 per cent of available moisture.

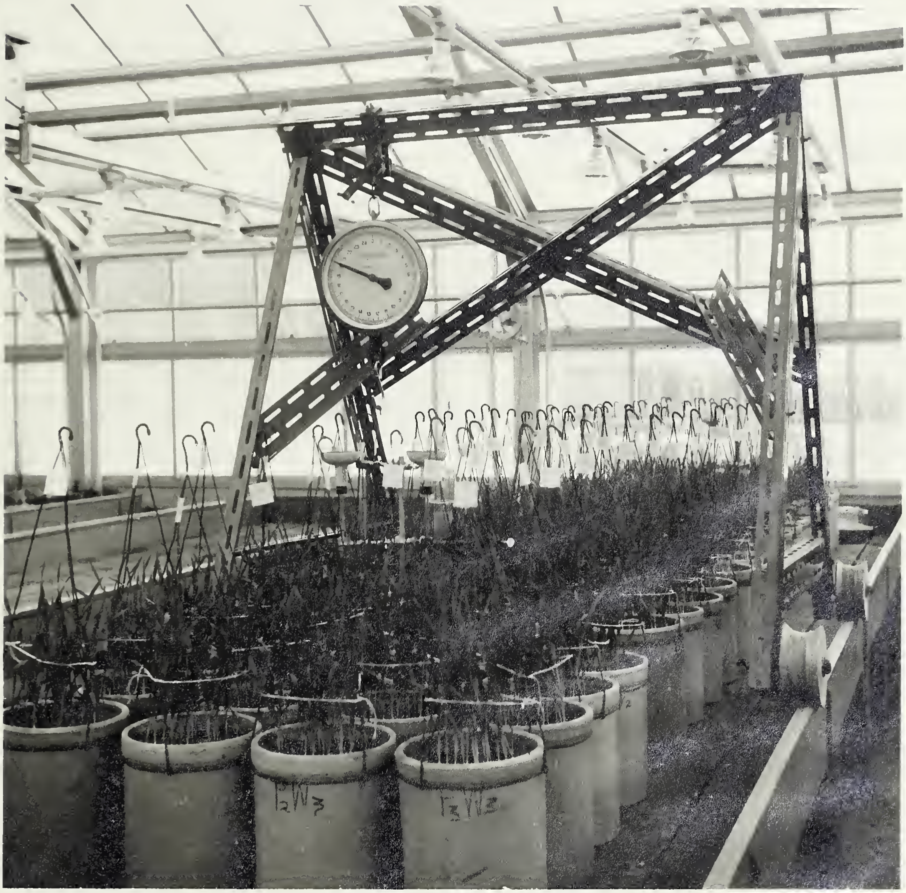
W_3 - as above but water when the soil moisture was reduced to 50 per cent of available moisture.

W_4 - as above but water when the soil moisture was reduced to 75 per cent of available moisture.

The scheduling and determination of amounts of watering was based on daily weighing of the pots throughout the test period. The apparatus used for these weighings is shown in figure III. After seeding and moistening the soil to field capacity, the weight of each pot was recorded. The weight for each pot when the soil moisture was depleted to the minimum level for the particular water treatment, was calculated. The daily losses in weight of each pot were taken to represent the daily use of water. The pots were watered when the daily weights reached the minimum amount, and each pot was treated separately. At each time of watering, the water was added while the pot was supported by the scale in quantity to bring the total weight up to that required for field capacity. Gains in weight of the barley plants growing in the pots were disregarded in the weighing and watering schedule, since the only object was to provide a basis for a range of soil moisture levels, and thus induce a range of total evapotranspiration.

The barley was seeded at the one-half inch depth. Thirty-three seeds were planted in each pot, and when the seedlings had grown to the two-leaf stage, the plant population was thinned to twenty-five plants per pot. The plants were harvested 51 days after emergence, at which time

Figure III Apparatus for weighing pots



In operation, the scale carriage was moved along the length of the bench. The scale and windlass assembly was movable along the top bar of the carriage. Thus all pots could be weighed without removing them from the bench. Note the Bellani plates below the scale. The instrument on the left was used for checking purposes.

they were in the late shot-blade stage of growth. The plant material was cut at the soil surface and oven dried at 70°C. for determination of total dry matter.

Soil samples for moisture determinations were taken with a soil tube from each pot at the time of harvest. The weight of the water remaining in the soil at that time, as calculated from these determinations, was then subtracted from the total weight of water applied to each pot during thetest. The remainder represented the total evapotranspiration for the growth period.

METEOROLOGICAL DATA

Weather records are kept as routine procedure at the Vauxhall substation (22). The meteorological plot is approximately a quarter of a mile from the plot site which was used in this study. The evaporation rate would vary but little in this distance, therefore the Bellani plate records as obtained at the meteorological plot were used. However, since rainfall is likely to vary significantly over such a distance, a standard rain gauge was installed at the experimental plot site. Temperature and evaporation records were taken at the meteorological plot.

As a check on the performance of the black Bellani plate under greenhouse conditions, two of these instruments were installed in conjunction with the pot experiment. Daily evaporation was recorded. The bench locations of these instruments are shown in figure II.

LABORATORY ANALYSES OF PLANT MATERIAL

The grain and the straw from selected treatment combinations of the plot experiment were analysed for total phosphorus. The treatment combinations were $P_o W_o$, $P_o W_3$, P_3W_o and P_3W_3, from each of the five replications. Oven dried and ground samples were ashed using HNO_3 and

HCL O_4 acids by the Giesking method as modified by Hoff (19), and adapted to the micro kjeldahl procedure. The phosphorus content was determined by the meta-vanadate colorimetric development, using a Bausch and Lomb colorimeter.

The dried, whole plant material from selected treatments of the pot experiment was also analysed for total phosphorus, using the above method. These treatments were W_1P_0, $W_1 P_3$, $W_3P_0$and $W_3 P_3$ from each of the five replications.

The nitrogen content of the grain samples from the same selected plot treatments, was also determined, using the Kjeldahl-Gunning method (33). Digestion catylist tablets containing $Cu SO_4 \not- HgO \not- K_2SO_4$ were used as the catylist, and sodium thiosulphate was added in the sodium hydroxide to precipitate the mercury. The ammonium distillate was collected in 4 per cent boric acid and titrated with N/14 sulfuric acid.

RESULTS AND DISCUSSION

A. FIELD PLOT EXPERIMENT

(1) Irrigation and Use of Water. A summary of the amounts of irrigation which were applied to the plots as imposed by the spring soil moisture levels and the soil moisture budget is presented in Table 2.

Table 2. Summary of dates and amounts of irrigation on the field plots.

	Inches of irrigation during the week ending:							
Plot Treatment	June	July				August		Season Total
	30	6	13	20	27	3	10	
W_1P_0	3.0-7.0*					5.2		9.0-13.0**
W_1P_1	5.0-7.6					5.2		11.0-13.6
W_1P_2	4.5-6.5					5.2		10.5-12.5
W_1P_3	4.0-8.0					5.2		10.0-14.0
W_2P_0	5.0-7.6			3.6			3.4	12.8-15.4
W_2P_1	2.5-8.0			3.6			3.4	10.2-15.8
W_2P_2	3.6-7.5			3.6			3.4	11.4-15.2
W_2P_3	4.0-8.0			3.6			3.4	11.8-15.8
W_3P_0	4.0-8.1		2.0	2.0	2.0	2.0	2.0	14.8-18.8
W_3P_1	5.5-8.1		2.0	2.0	2.0	2.0	2.0	16.2-18.8
W_3P_2	6.1-8.1		2.0	2.0	2.0	2.0	2.0	16.8-18.8
W_3P_3	3.5-8.1		2.0	2.0	2.0	2.0	2.0	14.2-18.8

* The range of amounts of irrigation which had to be applied to bring the soil moisture content up to field capacity on this date.

** The range in total irrigation water applied, including 0.7 inches applied to all plots by sprinkler on May 31.

The total irrigation applied ranged from 9.0 inches on one plot under

treatment W_1 to 18.8 inches on some of the plots under treatment W_3. Because of an error in timing the irrigation on the plots under treatment W_2 on July 20, these plots received 3.6 inches of water instead of 3.4 inches as was previously scheduled. This error was uniform for all of these plots and was relatively small; therefore it was not serious.

The average consumptive use of water in inches for the growing season for each of the water and phosphate treatment combinations is shown in Table 3, which also shows the appropriate L.S.D. Although the plot design was that of a balanced lattice, the data were analysed as a simple factorial design. This procedure was followed for all data which were statistically analysed.

Table 3. Consumptive use for the growing season.
Each figure is the average in inches of the consumptive use on 5 replications.

Water Treatment	Phosphate treatment P_0	P_1	P_2	P_3	Av. W
W_0	7.0	7.9	7.2	6.4	7.1
W_1	13.1	13.6	12.9	12.5	13.0
W_2	16.2	16.5	16.3	15.8	16.2
W_3	19.1	19.1	19.3	19.2	19.2
Av. P	13.8	14.3	13.9	13.5	

L.S.D. for W = 0.7 inches.

An example of the basic data used in calculating the consumptive use of water for each plot is given in appendix C. The total rainfall during the growing season was only 2.54 inches; therefore irrigation treatment had a marked effect on the total water used by the crop.

Irrigation level was highly significant in its effect on consumptive use, the increase being from an average of 7.1 inches for treatment W_0 to an average of 19.2 inches for treatment W_3. The effect on consumptive use, of phosphate fertilization level, however, was not significant.

(2) Yields. The average heights of the crop for each of the treatment combinations are shown in Table 4.

Table 4. Average height, in inches of the barley plants at time of harvest.

Water Treatment	Phosphate treatment P_0	P_1	P_2	P_3	Av. W
W_0	17	19	16	16	17
W_1	28	25	25	26	26
W_2	28	28	28	28	28
W_3	31	32	34	31	32
Av. P	26	26	26	25	

L.S.D. for W = 2.1 inches.

The effect of irrigation level on the height of the crop was again highly significant whereas the influence of phosphate level was not.

The average yield of total dry matter in hundredweight per acre for each of the treatment combinations is shown in Table 5.

Table 5. Average yields of total dry plant material in hundred-weight per acre.

Water		Phosphate	treatment		
Treatment	P_0	P_1	P_2	P_3	Av. W.
W_0	27.6	32.4	26.9	24.7	27.9
W_1	54.8	48.9	55.5	53.6	53.2
W_2	62.4	62.9	64.7	70.6	65.2
W_3	74.8	72.6	78.6	76.0	75.5
Av. P	54.9	54.2	56.4	56.2	

L.S.D. for W = 5.4 hundred-weight.

Increasing level of irrigation was highly significant in increasing the yield of total dry matter, but the effect of phosphate level was not significant. Each succeeding level of irrigation significantly increased yields of total dry matter over the preceeding lower level.

The average yield of threshed grain for each of the treatment combinations is shown in Table 6.

Table 6. Average yields of threshed grain in bushels per acre.

Water		Phosphate	treatment		
Treatment	P_0	P_1	P_2	P_3	Av. W
W_0	19.6	28.1	18.9	26.0	23.2
W_1	49.2	39.0	52.9	51.3	48.1
W_2	57.2	59.5	60.1	66.3	60.8
W_3	65.9	65.5	73.0	68.8	68.3
Av. P	48.0	48.0	51.2	53.1	

L.S.D. for W = 5.9 bushels.

Once again water treatment level was highly significant in increasing grain yield, but phosphate level was found to be not significant. The yields were erratic under treatments W_0 and W_1 but tended to be more uniform with the higher water treatments. Increasing levels of phosphate fertilization appeared to result in a slight increase in yield. The surface application of phosphate could not be expected to influence yields under conditions of limited precipitation since there would be little downward movement of phosphorus. However, with frequent irrigation and greater total amount of water applied, some phosphorus may have been carried down to the root feeding zone and thus made available for plant use.

The available phosphorus content of the soil was 30 to 35 pounds per acre furrow slice, as determined by the Miller and Axley method (28). The soil used in this experiment was therefore fairly well supplied with phosphorus for plant growth, and responses to phosphate fertilization would not be very large. Irrigated soils in the Brown soil zone usually show good responses to phosphate fertilization. The only explanation offered for the unusual results in this test is that the plots were located on relatively new land. The plot area was brought under cultivation from native prairie in 1952, and only three crops had been grown on it up to the end of 1956. It was summerfallowed in 1955.

The average yields of straw for each treatment combination is shown in Table 7.

Table 7. Average yields of straw in hundred-weight per acre.

Water Treatment	Phosphate P_0	treatment P_1	P_2	P_3	Av. W
W_0	17.8	18.7	17.6	17.3	17.8
W_1	30.9	30.3	30.0	28.6	30.0
W_2	31.6	31.4	33.2	35.6	33.0
W_3	40.0	38.3	40.5	38.3	39.3
Av. P	30.1	29.7	30.3	30.0	

L.S.D. for W = 3.2 hundred-weight per acre.

The influence of irrigation level on straw yield was highly significant, but that of phosphate treatment was not significant. All comparisons within water levels were significant except that of W_1 and W_2. Average straw yields did not vary as much as the average yields of grain, and phosphate level had no apparent effect within any of the irrigation treatment levels. This is to be expected since yields of grain were not influenced by the phosphate fertilization, and yields of grain should be influenced by phosphate supply to a greater extent than yields of straw.

(3) Efficiency of Water Use. The average bushels per acre yield of grain per inch of consumptive use of water for each of the treatment combinations is shown in Table 8.

Table 8. Average bushels per acre per inch of consumptive use.

Water Treatment	Phosphate P_0	treatment P_1	P_2	P_3	Av. W
W_0	2.71	3.46	2.57	3.97	3.18
W_1	3.76	2.87	4.09	4.17	3.72
W_2	3.51	3.63	3.69	4.21	3.76
W_3	3.45	3.42	3.78	3.54	3.55
Av. P	3.36	3.34	3.53	3.97	

Water treatment effect and phosphorus treatment effect were both not significant. It appeared that the soil moisture levels for the plots under irrigation treatment W_0 approached the point where plant growth would be entirely prevented. This would account for the very low yields of grain per unit of consumptive use where irrigation was not applied. There was little difference between the average bushels per acre per inch of water use under the other water treatments.

The average pounds of water required by the crop, to produce one pound of dry plant material is given for each treatment combination in Table 9.

Table 9. Ratios of water use to total dry matter produced.

Water Treatment	Phosphate treatment P_0	P_1	P_2	P_3	Av. W
W_0	682	634	674	737	682
W_1	553	663	536	551	576
W_2	594	621	578	516	577
W_3	586	606	568	599	590
Av. P	604	631	589	601	

L.S.D. for W = 78 pounds T.D.M./pound of use.

The effect of irrigation level was significant, but phosphate fertilization level was not significant in decreasing the amount of water required to produce unit total dry plant material. The ratios for water treatments W_1, W_2, and W_3 were each significantly lower than the ratio for W_0 but all other comparisons were not significant. The failure of the phosphate treatments to show an influence on the efficiency of water use is to be expected, since the phosphate treatments in this experiment did not

influence yields of total dry matter, threshed grain or straw. This failure of the phosphate treatment levels to influence yields of total dry matter and the efficiency of water use was probably due to a combination of the following causes:

(a) The soil was naturally well supplied with available phosphorus. This has already been discussed.

(b) The phosphate fertilizer was broadcast on the surface of the soil, rather than at seed depth. Since phosphorus compounds do not readily move in the soil, the fertilizer phosphorus was not available for plant use because it was not in the root feeding zone. If any downward movement of phosphorus did occur, it would have been under the higher irrigation treatments.

(c) Inherent variations in the soil may have accounted for a large part of the total variation. This residual variation tended to give large error mean squares, which reduced the precision of the experiment.

(4) Quality of Plant Material. The averages of the bushel weights of the barley are presented in Table 10.

Table 10. Average bushel weights of barley.

Water Treatment	Phosphate treatment P_0	 P_1	 P_2	 P_3	 Av. W
W_0	49.5	49.1	48.9	48.7	49.0
W_1	48.6	47.0	47.5	49.6	48.2
W_2	53.4	52.6	52.1	52.3	52.6
W_3	52.5	52.1	52.1	52.3	52.2
Av. P	51.0	50.0	50.0	50.6	

L.S.D. for W = 3.1 pounds.

Irrigation level effect on bushel weights was highly significant, but phosphate fertilizer treatment effect was found to be not significant. Both treatments W_2 and W_3 were significantly better than treatments W_0 and W_1 but all other comparisons were not significant. The limited precipitation during the growing season was evidently not enough to properly fill the grain where it was not given supplemental water, and perhaps the drop in soil moisture content before the last irrigation application on the plots of treatment W_1 was sufficient to inhibit the filling of the grain under this treatment as well.

The average phosphorus content of the threshed grain from treatment combinations W_0P_0, W_0P_3, W_3P_0, and W_3P_3 is given in Table 11.

Table 11. Average per cent phosphorus in the barley from selected treatment combinations.

Water Treatment	Phosphate treatment P_0	P_3	Av. W
W_0	0.20	0.20	0.20
W_3	0.23	0.26	0.24
Av. P	0.22	0.23	

L.S.D. for W = 0.031.

The data, which is summarized in Table 11, was analysed as a simple 2 x 2 factorial in five replications. Irrigation treatment effect on per cent phosphorus content of the grain was significant, but phosphate treatment effect was not.

The average per cent phosphorus in the straw from the same treatments is shown in Table 12.

Table 12. Average per cent phosphorus in the straw from selected treatment combinations.

Water Treatment	Phosphate treatment P_0	P_3	Av. W
W_0	0.07	0.08	0.075
W_3	0.05	0.06	0.055
Av. P	0.06	0.07	

The results of the phosphorus determinations on the straw gave very erratic results, and neither irrigation nor phosphate treatment was significant.

The average per cent nitrogen in the grain of treatment combinations W_0P_0, W_0P_3, W_3P_0, and W_3P_3 are given in Table 13.

Table 13. Average per cent nitrogen in the grain from selected treatment combinations.

Water Treatment	Phosphate treatment P_0	P_3	Av. W
W_0	2.51	2.41	2.46
W_3	1.76	1.69	1.73
Av. P	2.14	2.05	

The nitrogen content was not significantly influenced by either water or phosphate treatment, because of the variability in the original data. However, increased water treatment did appear to decrease the nitrogen content of the grain.

Summarizing the effect of the irrigation and phosphate treatments on the quality of the plant material produced, it has been

shown that watering level was the only treatment to have had an effect. Again this would indicate that either the soil phosphorus was in plentiful supply, the fertilizer phosphorus was not available for plant use because of placement, or inherent variation in the soil between plots was great enough to nullify the effect of the treatments.

B. GREENHOUSE EXPERIMENT

(1) Watering and Evapotranspiration. The numbers of times of watering for each of the pots under the various treatment combinations as imposed by the weighing method of scheduling the times of application, are shown in Table 14.

Table 14. Numbers of times of watering the greenhouse pots.

	Replication					
Treatment	I	II	III	IV	V	Average
W_1P_0	2	2	3	2	2	2.2
W_1P_1	2	2	3	2	2	2.2
W_1P_2	2	2	3	2	2	2.2
W_1P_3	2	2	2	2	2	2.0
W_2P_0	6	4	6	5	6	5.4
W_2P_1	5	6	6	6	6	5.8
W_2P_2	6	6	6	6	6	6.0
W_2P_3	6	6	6	6	7	6.1
W_3P_0	9	9	7	10	11	9.2
W_3P_1	10	9	9	10	11	9.8
W_3P_2	9	10	11	11	12	10.6
W_3P_3	10	10	12	11	12	11.0
W_4P_0	17	17	19	18	19	18.0
W_4P_1	17	19	20	19	19	18.8
W_4P_2	18	20	20	20	19	19.4
W_4P_3	20	20	20	20	20	20.0

These data show that to maintain the scheduled water levels, the pots were watered from 2 to 20 times. They also show that the frequency of irrigation was increased slightly in the higher water treatments as the phosphate level of treatment was increased.

The average evapotranspiration in pounds of water per pot for the various treatment combinations is given in Table 15.

Table 15. Average evapotranspiration in the greenhouse in pounds of water.

Water Treatment	Phosphate treatment P_0	P_1	P_2	P_3	Av. W.
W_1	5.8	6.4	5.9	5.5	5.9
W_2	9.3	10.1	9.2	10.2	9.7
W_3	10.6	11.4	12.0	12.4	11.6
W_4	11.5	12.2	12.0	12.7	12.1
Av. P	9.3	10.0	9.8	10.2	

L.S.D. for W and P = 0.7
L.S.D. for W x P = 0.5 pounds.

Watering levels and phosphorus levels were highly significant and the interaction, water x phosphorus, was significant. Increased watering level and increased phosphate fertilization level each tended to increase the evapotranspiration during the growing period, and the presence or absence of either factor influenced the effect of the other.

(2) Yields of Total Dry Matter. The average oven-dry weights of plant material harvested from the pots under the treatment combinations are shown in Table 16.

Table 16. Average yields of total dry plant material in grams.

Water Treatment	P_0	P_1	P_2	P_3	Av. W
W_1	4.8	5.2	5.2	5.2	5.1
W_2	7.6	8.9	8.3	9.0	8.7
W_3	8.3	9.3	9.9	9.9	9.4
W_4	8.3	8.9	9.1	9.5	9.0
Av. P	7.2	8.1	8.1	8.4	

L.S.D. for W and P = 0.4.

Watering level and phosphate fertilization level each were highly significant in their influence upon these yields, but the interaction was not significant. There was a significant increase in yield for the pots under water treatment W_2 over those under W_1 and a significant increase for those under W_3 over W_2. Water treatment W_4, compared to W_3, caused a yield decrease which just reached the significant level. There also was a significant increase for all phosphate treatments P_1, P_2, and P_3 over P_0 but no significant differences between the treatments where phosphate had been applied. This would suggest that watering treatment W_4 exceeded the optimum level for plant growth, and that phosphate fertilizer supply above 40 pounds per acre of P_2O_5 was in luxury supply. This conclusion confirms, at least in part, indication shown by the field plot experiment that the available soil phosphorus was in fairly good supply.

(3) Efficiency of Water Use. The average amounts of water required by the pots under the various treatment combinations to produce

unit total dry matter are shown in Table 17.

Table 17. Average ratios of evapotranspiration to total dry plant material produced.

Water Treatment	Phosphate treatment P_0	P_1	P_2	P_3	Av. W
W_1	559	521	523	502	526
W_2	555	515	504	518	523
W_3	581	556	547	567	563
W_4	635	620	599	604	614
Av. P	582	553	543	548	

L.S.D. for W and P = 24.

Watering level and phosphate fertilization level each were highly significant in their effect on the efficiency of water use. Each increase of watering level above treatment W_2 resulted in a significant increase in the amount of water required to produce unit total dry plant material. The phosphate fertilizer levels, P_1, P_2, and P_3, all significantly decreased the ratio from that of P_0, but were not significantly different in this respect among themselves. Had the higher phosphate treatments resulted in significantly increased yields of total dry plant material, the test would have likely shown increased efficiencies of water use beyond the lowest level of phosphate application.

The difference in the influence of watering level on the efficiency of water use, which was shown between the field plot test and the greenhouse test, is explainable on the basis of differences between field

plot and greenhouse pot conditions. Because of the limited soil volume in the greenhouse pots, watering had to be frequent to maintain the soil moisture content at the desired level. The soil surface in the pots was moist for a large part of the time. In the field there is a very much larger volume of soil for root feeding and moisture storage, and irrigations were applied with much less frequency and in larger amounts. The soil surface on the field plots was dry for a large portion of the time. Evaporation from the soil surface in greenhouse pots thus may be assumed to constitute a disproportionately large amount of total evapotranspiration, when the soil moisture is maintained close to field capacity.

(4) Phosphorus Content. The average results of the phosphorus analysis of greenhouse plant material from treatment combinations W_1P_0, W_1P_3, W_3P_0, and W_3P_3, for the five replications, are given in Table 18.

Table 18. Average per cent phosphorus in greenhouse plant material from selected treatments.

Water Treatment	Phosphate treatment P_0	P_3	Av. W
W_1	0.35	0.52	0.44
W_3	0.28	0.44	0.36
Av. P	0.32	0.48	

L.S.D. for W and P = 0.03.

The phosphorus analysis showed that there was a significant increase in the phosphorus content of the total plant material from the pots as the phosphate fertilizer level was increased, and a significant decrease in this value as the watering level was increased. Comparison

of these results with the phosphorus analysis of the plant material from the field plots, where treatment effects were not significant, again indicates that improper placement of the phosphate fertilizer, or extraneous variability in the plot experiment, was the cause of the lack of crop response to phosphate in that test.

C. ESTIMATING POTENTIAL EVAPOTRANSPIRATION

The potential evapotranspiration, as calculated by applying the formulae of Blaney and Criddle, Penman, and Thornthwaite to the meteorological data obtained at the Vauxhall substation for May, June, July, and August is given in Table 19. The evapotranspiration as estimated from the black Bellani plate evaporation for June, July, and the first 21 days of August, using the conversion factor proposed by Robertson (45) is also given.

Table 19. Potential evapotranspiration in inches based on meteorological data.

	Method			
Month	Blaney & Criddle	Penman	Thornthwaite	Robertson
May	4.70	5.09	3.51	--
June	5.00	4.66	4.18	5.35
July	5.88	7.60	5.34	8.87
August	4.72	4.81	4.08	3.85*
Total	20.30	22.16	17.11	18.07
Total; June, July, August	15.60	17.07	13.60	18.07*

* Data to August 21 only.

Examples of the calculations involved in the derivation of these values by the various methods are given as follows:

(a) Blaney and Criddle method for the month of May:

Formula ---- $U = KF = \lesssim kf$

where U = consumptive use for the year

kf = consumptive use for each month

and $f = \frac{tp}{100}$

when t = mean month temp., degrees F.

= 55.5 for May.

p = monthly per cent of daytime hours of the year.

Daytime hours of the year = 365 x 12 = 4,380 hours.

Daytime hours in May at 12 hours per day = 31 x 12 = 372 hours.

Factor to convert 12-hour day to actual day for 50^{o}N. Lat. for the month of May = 1.33. From tables in Climatology (63).

Actual daytime hours in May = 372 x 1.33 = 494 hours.

Therefore p for May $= \frac{494}{4380} \times 100 = 11.3$

And, $f = \frac{55.5 \times 11.3}{100}$

$= 6.27.$

The k value was taken to be 0.75. This value is given by Blaney (4) as being applicable in calculating the consumptive use of water for small grains in the semi-arid areas of western United States.

Consumptive use for May, calculated by the Blaney and Criddle method = 6.27 x 0.75

= 4.70 inches.

(b) Penman method for the month of May:

Formula ---- $E_t = fE_o$

where E_t = potential evapotranspiration.

E_o = evaporation from a free water surface.

f = a factor which varies according to season.

For May, the evaporation at Vauxhall from a free water surface was 6.36 inches. The factor f, for the summer months, is given by Penman (36) to be 0.8.

Potential evapotranspiration (consumptive use) for

May = 0.8×6.36

= 5.09 inches.

(c) Thornthwaite method for the month of May:

Formula ---- $e = 1.6 \ (10\ t/I)^a$

where e = the monthly evapotranspiration in centimeters.

t = mean monthly temperature in degrees centigrade.

I = heat index, which equals the sum of the monthly heat index values, each of which equals $(t/5)^{1.514}$.

a = an imperical coefficient that varies with I.

In working out the evapotranspiration from this formula, tables and nomograms are used to simplify the calculations. Steps involved in this procedure are:

(1) Obtain the heat index I, which is the summation of the heat indices for each of the 12 months of the year. These are obtained from a table which is included in the reference (63). The mean monthly temperatures in degrees centigrade for 1957 at Vauxhall, together

with the heat indices for each month were as follows:

Month	Mean °C.	i
January	0	0
February	0	0
March	0	0
April	5.4	1.13
May	13.0	4.27
June	15.2	5.11
July	19.4	7.81
August	16.3	5.96
September	13.7	4.60
October	0.2	0.01
November	0	0
December	0	0
Sum of i =		28.89

(2) Prepare the nomogram and from this determine the unadjusted potential evapotranspiration for each month using the mean monthly temperatures in degrees centigrade. For May this was 6.7 cm. of unadjusted potential evapotranspiration.

(3) Apply the appropriate adjustment factor for the degrees north or south latitude, as determined from the tables. For May, the adjustment factor is 1.33. Thus, the adjusted potential evapotranspiration for May was 6.7 x 1.33 = 8.91 cm. = 3.51 inches. The necessary tables and nomogram for carrying out these calculations are given in the appendix E.

(d) The Robertson conversion of black Bellani plate evaporation in cc. to inches of potential evapotranspiration by multiplying cc. evaporation x 0.0034: For May the Bellani plate evaporation totaled 1,573 cc. Potential evapotranspiration by this method

= 1,573 x 0.0034

= 5.35 inches for May.

The calculated potential evapotranspiration varied considerably with the Penman method giving the highest total value for the four months, and the Thornthwaite method giving the lowest value. For the three months which corresponded to the growing season of the crop used in the plot experiment, the Robertson method gave the highest total estimate and the Blaney and Criddle method gave the lowest.

The plots of the field experiment gave the highest yields when they were irrigated with the greatest frequency, and were given the most water (see Table 6), and these highest yielding plots also showed the highest average consumptive use of water for the growing season. The consumptive use for maximum yields on the field plots was from 19.0 to 19.3 inches. It would therefore appear that the Robertson method of determining evapotranspiration from the black Bellani plate evaporimeter data gave the closest estimate of the actual evapotranspiration. No provision was made in this experiment to determine monthly consumptive use of water on the plots. It is therefore impossible to compare the calculated evapotranspiration using the various methods, with the actual use on a monthly basis.

In the greenhouse the total average evaporation from the two black Bellani plates was 413 cc. of water for the growing period of the crop. Table 20 presents the average evapotranspiration from the pots of the various water and phosphate treatment combinations, expressed in inches depth of water from the soil area of the pot, together with the factor which would have to be used to convert the Bellani plate evaporation to the evapotranspiration as actually determined.

Table 20. Evapotranspiration and conversion factors.
(Note -- the factor is the coefficient required to convert the Bellani plate evaporation in cc. to the evapotranspiration figure obtained.)

Phosphorus treatment		W_1	W_2	W_3	W_4
P_0	Evapotransp. (in.)	5.5	9.0	10.5	11.3
	Factor	0.0133	0.0218	0.0254	0.0273
P_1	Evapotransp. (in.)	6.2	10.0	11.3	12.1
	Factor	0.0150	0.0242	0.0273	0.0293
P_2	Evapotransp. (in.)	6.0	9.1	12.0	12.0
	Factor	0.0145	0.0220	0.0290	0.0290
P_3	Evapotransp. (in.)	5.8	10.2	12.3	12.8
	Factor	0.0140	0.0247	0.0297	0.0309

The data in Table 19 show that the factor which would convert the Bellani plate evaporation in cc. to inches of evapotranspiration would, under greenhouse conditions, be from 4 to 10 times as large as the factor 0.0034 proposed by Robertson as being applicable under field conditions. Evidently, transpiration rates were relatively high under conditions of the greenhouse experiment. The plants evidently responded in this respect to some factors which did not influence proportionately the evaporation from the black Bellani plate evaporimeter. The influence of individual climatic factors, which form part of the total environment of the plant, upon the magnitude of evapotranspiration was, however, beyond the scope of this study.

The soil surface in the pots under the higher levels of moisture treatment was wet for a major part of the time, as has been discussed under the efficiency of water use in the greenhouse. The larger evapotranspiration compared to the Bellani plate evaporation in the greenhouse experiment would be due, at least in part, to the large losses of water as evaporation from the soil surface.

CONCLUSIONS

The yields of plant material, in both the field plot and the greenhouse experiments were influenced more by water treatment than by phosphate fertilizer treatment. The soil used in the experiments contained 30 to 35 pounds of available phosphorus per acre furrow slice as determined in this experiment; therefore phosphorus supply in the soil was not likely to be a limiting factor for plant growth.

The yields of grain on the plots were increased by irrigation from an average of 24 bushels per acre for the non-irrigated treatments to an average of 68 bushels per acre for the treatments which were irrigated six times during the season, and received 15 to 19 inches of supplemental water. The maximum yields of grain where the phosphate fertilizer was applied did not differ statistically from the yields where no phosphate fertilizer was applied.

The yields of total dry plant material from the greenhouse pots were about doubled by increasing the minimum allowable soil moisture content from the wilting point to 50 per cent of the available water-holding capacity of the soil. Further increase of this minimum level to 75 per cent resulted in an appreciable decrease in yield. Increasing phosphate supply level in the greenhouse experiment slightly increased yields of total dry matter. This effect was statistically significant, partly because better control of extraneous variables was possible than in the plot experiment, and possibly because the phosphate fertilizer was placed below the seed and was more readily available for use by the plants, than when broadcasted on the soil surface, as was done in the plot experiment.

The quality of the barley in the field plot experiment, as evaluated by bushel weight, phosphorus content and nitrogen content, was also influenced to a greater extent by water treatment than by phosphate treatment. The bushel weights were significantly increased by increasing irrigation level, but were not influenced by phosphate supply. Increased irrigation level appeared to increase the phosphorus content of the grain. Per cent nitrogen of the grain appeared to be decreased by increasing levels of both phosphate fertilization and irrigation. In the greenhouse, the phosphorus content of the dry plant material was also increased by phosphate fertilizer supply, but appeared to be decreased by increasing levels of water supply.

The efficiency of water use in the field plots was significantly influenced by irrigation level, but was not significantly influenced by phosphate fertilizer level. The pounds of water required to produce one pound of total dry plant material, exclusive of roots, varied from an average of 572 for the most frequently irrigated plots, to an average of 682 for the plots which were not irrigated.

In the greenhouse, the efficiency of water use was significantly influenced by both water supply and phosphate fertilizer level. Increasing fertilization tended to decrease the amount of water required to produce unit total dry matter, but increasing moisture level tended to increase this value. The pounds of water required to produce one pound of total dry matter was reduced by increasing levels of phosphate fertilization from an average of 582 pounds for all treatments not fertilized with phosphate to an average of 543 pounds for all treatments which received phosphate fertilizer at 80 pounds per acre of P_2O_5. The increase in this value, due to watering level, was from an average of 526 pounds for all treatments

under the lowest level of watering, to an average of 614 pounds for all treatments under the highest levels of watering.

In summary, the efficiency of water use was increased by phosphate fertilization in the greenhouse experiment, but was not increased by phosphate fertilization in the field plot experiment. On the other hand the efficiency was increased by increasing irrigation level in the field plots, but was decreased by increased watering level in the greenhouse.

In comparing the estimates of potential evapotranspiration calculated from meteorological data using some of the formulae which have been proposed for this purpose, with the actual consumptive use for maximum yields in the field plot experiment, it was found that the estimate based on the black Bellani plate evaporimeter data most closely approximated the actual value. Provision was not made in the experiment to obtain consumptive use values for individual months, and so comparisons with the calculated values were not possible on a monthly basis.

The relationship between evaporation in cc. from the black Bellani plate and the use of water from the field plots did not hold under greenhouse conditions. Evapotranspiration, compared to evaporation as measured by this instrument was 4 to 10 times as large in the greenhouse as it was for the maximum yielding field plots.

REFERENCES

1. Alberta Advisory Fertilizer Committee. Fertilizers in Alberta. Publ. no. 5. Prov. of Alberta. Dept. of Agr. 1956.

2. Amberger, A. Water consumption as affected by fertilizing Z. Acher-u. Pfl. Bau. 99. 45-54. 1955. Abstract in Soils and Fert. 18. 249. 1955.

3. Baver, L. D. Soil physics. 3rd ed. John Wiley and Sons, Inc. N.Y.1956.

4. Blaney, H. F. Consumptive use of water. Proc. Amer. Soc. Civ. Eng. 77. Separate no. 91. 1951.

5. Bowser, W. E. and T. W. Peters. Soil survey of Red Deer Sheet. Bull. no. 51. Univ. of Alberta. 1951.

6. Bowser, W. E. and A. G. Mc Calla. Cropping for profit and permanency. Bull. no. 44. Dept. of Extension. Univ. of Alberta. 1956.

7. Briggs, L. J. and H. L. Shantz. The water requirements of plants. U.S.D.A. Bur. Plant Ind. Bul. 284-285. 1913 (In Expt. Sta. Record 29. 826. 1915).

8. Cochran, G. C. and G. M. Cox. Experimental designs. 2nd ed. John Wiley and Sons, Inv., N.Y. 1957.

9. Criddle, W. D. Consumptive use of water on irrigated land. Proc. Amer. Soc. Civ. Eng. 77. Separate no. 98. 1951.

10. Dean, L. A. Yield of phosphorous curves. Soil Sci. Soc. Amer. Proc. 18. 462-466. 1954.

11. Ferguson, W. S. and W. Michalyna. Consumptive use of water as influenced by fertilizer applications. First Annual Manitoba Soil Sci. Meeting. 1957.

12. Fried, M. and L. A. Dean. A concept concerning the measurement of available soil nutrients. Soil Sci. 73. 263-271. 1952.

13. Gardner, W. and D. Kirkham. Determination of soil moisture by neutron scattering. Soil Sci. 73. 391-402. 1952.

14. Gareau, L. Some effects of commercial fertilizers on yield and quality of forage crops in Alberta. Msc. Thesis. Univ. of Alberta 1955.

15. Giesking, J. E. , N. I. Snider and C. N. Getz. Destruction of organic matter in plant material by use of nitric acid and perchloric acids. Ind. Eng. Chem. Anal. Ed. 7. 185-186. 1935.

16. Halstead, M. H. and W. Covey. Some meteorological aspects of evapotranspiration. Soil Sci. Soc. Amer. Proc. 21. 461-464. 1957.

17. Hanks, R. J. and C. B. Tanner. Water consumption by plants as influenced by soil fertility. Agron. J. 44. 98-100. 1952.

18. Hemwell, J. B. The role of soil clay minerals in phosphorus fixation. Soil Sci. 83. 101-108. 1957.

19. Hoff, D. J. Fertility studies with radioactive and non-radioactive sulfur on grey wooded soils of Alberta. MSc. Thesis. Univ. of Alberta. 1953.

20. Hopkins, J. W. Weather and wheat yield in western Canada. I Influence of rainfall and temperature during the growing season on plot yields. Can. J. Research. 12. 306-334. 1935.

21. Hopkins, J. W. Weather and wheat yield in western Canada. II Influence of preseasonal precipitation on plot yields. III Relation between precipitation and agricultural yield. Can. J. Research C 14. 229-244. 1936.

22. Jacobson, W. L. Unpublished data. Irrigation Subst.Vauxhall, Alberta 1953-57.

23. Kitchen, H. B. editor. Diagnostic techniques for soils and crops. Amer. Potash. Inst. Wash. D.C. 1948.

24. Lemon, E. R., A. H. Glaser, and L. E. Satterwhite. Some aspects of the relationship of soil plant and meteorological factors in evapotranspiration. Soil Sci. Soc. Amer. Proc. 21. 464-468. 1957.

25. Livingston, B. E. Atmometers of porous porcelain and paper; their use in physiological ecology. Ecology 16. 438-472. 1935.

26. Meyer, S. M. and D. B. Anderson. Plant physiology. 2nd ed. D. Van Norstand Company Inc. Toronto. 1955.

27. Miller, C. E. Plant physiology. 2nd ed. Mc Graw-Hill Book Company Inc. New York. 1938.

28. Miller, J. R. and J. H. Axley. Correlation of chemical soil tests for available phosphorus with crop response, including a proposed method. Soil Sci. 82. 117-127. 1956.

29. Mitchell, J. A review of tracer studies in Saskatchewan on the utilization of phosphates by grain crops. J. Soil. Sci. 8. 73-85.1957.

30. Mitchell, J. The effect of phosphatic fertilizers on summerfallow wheat crops in certain areas of Saskatchewan. Sci. Agr. 26. 556-577. 1946.

31. Mitchell, J., H. C. Moss and J. S. Clayton. Soil survey of Southern Saskatchewan. Soil Survey Report no. 12. Can. Dept. of Agr. 1944.

32. Moller, J. and T. Mogensen. Use of an ion exchanger for determining available phosphorus in soils. Soil Sci. 76. 297-306. 1953.

33. Official methods of analysis of the association of official agricultural chemists. Washington 4, D. C. 8th ed. 1955.

34. Olsen, S. R., C. V. Cole, F. S. Watanabe, and L. A. Dean. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. Circ. 939. U.S.D.A., Washington, D.C.1954.

35. Olsen, S. R. and M. Fried. Soil Phosphorus and fertility. Yearbook of agric. U.S.D.A. 1957.

36. Penman, H. L. Estimating evaporation. Trans. Amer. Geophysical Union. 37. 43-46. 1956.

37. Peterson, H. B., L. B. Nelson, and J. L. Pashal. A review of phosphate fertilizer investigations in 15 Western States through 1949. U.S.D.A. circ. 927. 1953.

38. Pierre, W. H. The phosphorus cycle and soil fertility. J. Am. Soc. Agron. 40. 1-14. 1948.

39. Powers, W. L. and M. R. Lewis. Irrigation requirements of arable Oregon soils. Oreg. Expt. Sta. Bull. 394. 1941.

40. Pruitt, W. O. Irrigation scheduling guide. Agr. Eng. 37. 180. 1956.

41. Pruitt, W. O. and M. C. Jensen. Determining when to irrigate. Agr. Eng. Mech. 36. 389-393. 1955. (Abstract in Soils and Fert. 18. 429. 1955).

42. Rennie, D. A. Variations in percentage phosphorus and protein content of wheat as induced by phosphorus fertilization treatment, soil type and season. Can. J. Agr. Sci. 36. 491-504. 1956.

43. Richards, L. A. editor. Diagnosis and improvement of saline and alkali soils. U.S.D.A. Agr. Handbook no. 60. 1954.

44. Ripley, P. O. Progress report, division of field husbandry, soils and agricultural engineering. Can. Dept. of Agr. 1936-1948.

45. Robertson, G. W. Latent evapotranspiration, its concept, measurement and application. Processed bull. Exptl. Farms Service. Can. Dept. of Agr. 1954.

46. Robertson, G. W. and R. M. Holmes. Estimating irrigation water requirements from meteorological data. Processed bull. Exptl. Farms Service, Can. Dept. of Agr. 1956.

47. Russell, E. J. Soil conditions and plant growth. 8th ed. Longmans, Green and Co. Toronto. 1950.

48. Sanderson, M. An experiment to measure potential evapotranspiration. Can. J. Research. C 26. 445-454. 1948.

49. Sanderson, M. The climates of Canada according to the new Thornthwaite classification. Sci. Agr. 28. 501-517. 1948.

50. Schofield, C. S. The water requirement of alfalfa. U.S.D.A. circ. 735. 1945.

51. Sell, O. E. and L. C. Olsen. The effect of surface applied phosphate and limestone on soil nutrients and pH of permanent pasture. Soil Sci. Soc. Amer. Proc. 11. 238-245. 1946.

52. Soil Test Work Group. Soil testing in the United States. Nat. Soil and Fert. Res. Comm. Beltsville, Maryland. 1951.

53. Soil Test Work Group. Soil tests compared with field, greenhouse and laboratory results. Tech. bull. no. 121. Agr. Expt. Sta. N. Carolina State Coll. 1956.

54. Sprague, V. G. and L. F. Graber. The utilization of water by alfalfa and bluegrass in relation to managerial treatments. Jour. Am. Soc. Agron. 30. 986-997. 1938.

55. Stanberry, C. O., C. D. Converse, H. R. Haise and O. J. Kelley. Effect of moisture and phosphate variables on alfalfa hay production on the Yuma Mesa. Soil Sci. Soc. Amer. Proc. 19. 303-310. 1955.

56. Stanford, G. and L. B. Nelson. Utilization of phosphorus as affected by placement. Corn in Iowa. Soil sci. 68. 129-135. 1949.

57. Staple, W. J. and J. J. Lehane. The conservation of soil moisture in Southern Saskatchewan. Sci. Agr. 32. 36-47. 1952.

58. Staple, W. J. and J. J. Lehane. Wheat yield and use of moisture on substations in Southern Saskatchewan. Can. J. Agr. Sci. 34. 460-468. 1954.

59. Taylor, S. A. and C. S. Slater. When to irrigate and how much to apply. Year book of Agric. U.S.D.A. 372-376. 1955.

60. Thorne, D. W. and H. B. Peterson. Irrigated soils, their fertility and management. 2nd ed. The Blackiston Company Inc. Toronto. 1954.

61. Thornthwaite, C. W. An approach toward a rational classification of climate. Geograph. Rev. 38. 55-94. 1948.

62. Thornthwaite, C. W. and J. R. Mather. The water budget and its use in irrigation. Yearbook of Agr. U.S.D.A. 346-358. 1955.

63. Thornthwaite, C.W. and J. R. Mather. Water balance. Publ. in Climatology. 8. 1-104. 1955.

64. Thom, C. C. and H. F. Holtz. Factors influencing the water requirements of plants. Wash. Agr. Expt. Sta. Bull. 146. 1917.

65. Toogood, J. A. and T. W. Peters. Comparison of methods of mechanical analysis of soils. Can. J. Agr. Sci. 33. 159-171. 1953.

66. Van Bavel, C. H. M. and F. V. Wilson. Evapotranspiration estimates as criteria for determining time of irrigation. Agric. Eng. 33 417-420. 1952.

67. Wyatt, F. A., J. D. Newton, W. E. Bowser, and W. Odynsky. Soil survey of Milk River sheet. Bull. no. 36. Univ. of Alberta. 1941.

68. Wyatt, F. A., J. D. Newton, W. E. Bowser and W. Odynsky. Soil survey of Rosebud and Banff sheets. Bul. no. 40. Univ. of Alberta. 1940.

69. Wyatt, F. A., J. D. Newton, W. E. Bowser and W. Odynsky. Soil survey of Sullivan Lake sheet. Bull. no. 38. Univ. of Alberta. 1938.

APPENDIX

A. PROCEDURE FOR AVAILABLE PHOSPHORUS DETERMINATION IN THE SOIL

REAGENTS:

1) Extracting reagent 0.03 with respect to both H_2SO_4 and NH_4F. Add 300 ml. of IN H_2SO_4 and 300 ml. of IN NH_4F to sufficient water to make 10 litres of solution.

2) Colorimetric reagents - a) Vanadate Solution. First prepare sulphuric acid 1:6, by adding 286 ml. conc. H_2SO_4 to 1714 ml. H_2O. Next prepare ammonium vanadate 0.25% by dissolving 2.5 gm. ammonium vanadate in 500 ml. of boiling water. Cool, and then add 60 ml. of 1:6 sulphuric acid to it. Cool the mixture to room temperature and dilute to 1 litre. Store in a brown bottle. b) Prepare ammonium molybdate 5% by dissolving 100 gm. in 2 litres of water.

3) Standard phosphorus solution. Dissolve 4.3935 gm. KH_2PO_4 and make up to 1 litre. Solution contains 1000 ppm of phosphorus.

Alequots of standard phosphorus solution were transferred to 50 ml. volumetric flasks so that after color development and making up to volume the solutions would cover the range 0 to 32 ppm of phosphorus. For color development, the reagents were added as follows, in the order shown:

1) 10 ml. of extracting solution.
2) Distilled water to give a total volume of approximately 25 ml.
3) 5 ml. of 1:6 H_2SO_4. Mix thoroughly.
4) 5 ml. of 0.25% Ammonium Vanadate. Mix thoroughly.
5) 5 ml. 5% Ammonium Molybdate. Mix thoroughly.
6) Distilled water to bring volume up to 50 ml. Mix thoroughly.

After allowing to stand for 15 minutes, the intensity of color developed in the solutions was then determined using a Fisher Spectrophotometer, with a 425 mu filter, using the A scale readings. The A scale

readings may be defined by the formula $100 \times \log \frac{100}{T}$, where

T = % transmittance.

EXTRACTION AND COLOR DEVELOPMENT PROCEDURE

1) Place 5.0 gm. of soil in 50 ml. erlenmeyer flasks.
2) Add ½ teaspoon carbon black.
3) Add 25 ml. extracting solution.
4) Shake on shaking machine for one minute.
5) Filter immediately, using gravity filtering, allowing five minutes.
6) Transfer 10 ml. of extract to 50 ml. erlenmeyers and develop color by
    a) Add 2 ml. 1:6 H_2SO_4. Mix thoroughly.
    b) Add 2 ml. Ammonium Vanadate solution. Mix thoroughly.
    c) Add 2 ml. Ammonium Molybdate solution. Mix thoroughly.
7) Allow 15 minutes for full color development.
8) Read on spectrophotometer.

B. PHOSPHORUS DETERMINATION IN PLANT MATERIAL

NITRIC-PERCHLORIC ACID DIGESTION PROCEDURE FOR MINERAL CONSTITUENTS:

Micro Kjeldahl Method

1. Weigh about 2.4 g. into drying pans.

2. Dry in oven for about 4 hours or overnight at 110°C.

3. Weigh on the analytical balance and transfer without filter paper into Kjeldahl flasks. Add 2 or 3 glass beads to each Kjeldahl.

4. Add 25 cc. of nitric acid (dil 3:1), rinsing the neck of the Kjeldahl flask and leave for about 2 hours with occasional shaking.

5. Leave on overnight on digester, rheostat at 40. Fume cupboard window closed. Do not put on glass fume hood.

6. Cool down in the morning and add 10 cc. of mixture of 5 parts perchloric acid, 6 parts water, 2 parts nitric acid. Put on aluminum

foil, especially around the neck and part of bulb.

7. Put on digester rheostat set at 40 and try to bring the rheostat setting up to 75 in about 1 - 2 hours, taking care that the flasks do not bump and the liquid is boiling gently.

8. When all the nitric acid is evaporated and the white fumes of the perchloric acid begin to form, put on glass fume hood, set rheostat at 90. In order to evaporate last traces, set rheostat at 100. Do not take to dryness unless liquid is clear.

9. Cool. Add 5 cc. of conc. HCl, evaporate without glass fume hood. Start heating with rheostat at 70, then to remove last traces set rheostat at 100.

10. Repeat 9.

11. Add 20 cc. of 1N HCl, loosen up residue using a stirring rod with policeman and filter through qualitative (No. 1 Whatman) filter paper into 200 cc. volumetric flask.

DETERMINATION OF PHOSPHORUS CONTENT

Using appropriate alequots of the filtrate determine the phosphorus content using the colorimetric procedure listed for available soil phosphorus determination.

C. EXAMPLE OF BASIC DATA FOR CONSUMPTIVE USE CALCULATION

An example of the basic data used in calculation of the consumptive use of water for the growing season on the various plots is given in table 1A. The data are for all plots under irrigation treatment W_3.

Table 1A. Data required to calculate Consumptive Use in inches

Rep.	Phos. Treat.	Spring Soil Moist.	Total Irr.	Fall Soil Moist	Cons. Use	Ave. Cons. Use
A	P_o	7.08	18.25	9.03	18.84	
B	P_o	9.35	14.80	8.48	18.21	
C	P_o	6.67	18.84	6.88	21.17	19.1
D	P_o	7.95	17.25	9.25	18.49	
E	P_o	9.75	15.20	8.82	18.67	
A	P_1	6.69	18.83	8.35	19.71	
B	P_1	9.19	16.25	10.76	17.22	
C	P_1	7.47	17.80	7.90	19.91	19.0
D	P_1	6.47	18.80	7.72	19.89	
E	P_1	8.03	16.80	8.34	19.03	
A	P_2	8.15	17.25	8.16	19.78	
B	P_2	6.55	18.80	8.50	19.39	
C	P_2	7.73	17.80	9.12	18.95	19.3
D	P_2	8.36	17.80	8.76	19.94	
E	P_2	8.61	16.85	9.51	18.49	
A	P_3	9.04	16.25	8.11	19.72	
B	P_3	7.36	17.80	8.74	18.96	
C	P_3	6.74	18.80	8.27	19.81	19.2
D	P_3	6.59	18.80	9.47	18.46	
E	P_3	10.87	14.21	9.80	18.89	

Rainfall between spring and fall soil moisture sampling dates = 2.54 inches.

Consumptive use was calculated by adding the amounts irrigation and rainfall together and adjusting this total for changes in soil moisture content, spring to fall. Each soil moisture entry is an average of the moisture content of soil samples to the three foot depth taken at three locations on each plot.

D. EXAMPLE OF THE SOIL MOISTURE BUDGET

The soil moisture budget used in scheduling irrigations from Aug. 1 to Aug. 8 is shown in table 2A. The items in the column "Latent evapotranspiration (ins.)" are the daily Bellani plate evaporation in c.c. X 0.0034. An example of the calculations involved is as follows:

On August 4 the latent evapotranspiration was 0.29 inches. In treatment W_1 the adjusted potential evapotranspiration on that day was 0.6 X 0.29 = 0.17 inches. This quantity brought the cumulative soil moisture deficit below field capacity up to 5.20 inches. Since this was the maximum allowable deficit for water treatment W_1 the plots were irrigated on August 5, applying 5.2 inches of water. On that day the potential evapotranspiration was 0.18 inches and when adjusted for this water treatment was 0.14 inches. Also, 0.01 inch of rain occurred on August 5. Therefore the deficit on August 5 was 5.20 - (5.20 + 0.01) + 0.14 = 0.13 inches. On August 6 the adjusted potential evapotranspiration was 0.18 X 0.6 = 0.11 inches. The soil moisture deficit for that day was therefore 0.13 - 0.13 + 0.11 = 0.11. For August 7 the adjusted potential evapotranspiration was 0.26 X 0.6 = 0.16. The deficit for August 7 was then 0.11 + 0.16 = 0.27 inches.

E. TABLES AND NOMOGRAM FOR THORNTHWAITE METHOD OF CALCULATING POTENTIAL EVAPOTRANSPIRATION

The monthly values of i (monthly heat index) corresponding to the monthly mean temperatures, are given in table 3A.

The mean possible duration of sunlight at 50° latitude North and South expressed in units of 30 days of 12 hours each, is as follows:

January	0.74
February	0.78
March	1.02
April	1.15
May	1.33
June	1.36
July	1.37
August	1.25
September	1.06
October	0.92
November	0.76
December	0.70

(From Climatology, Vol. VIII no. I)

The nomogram for Vauxhall for 1957, which was used to determine the unadjusted potential evapotranspiration in cm. for each month from the mean monthly temperatures is shown in figure IA.

Table 2A. Example of soil moisture budget field plots.

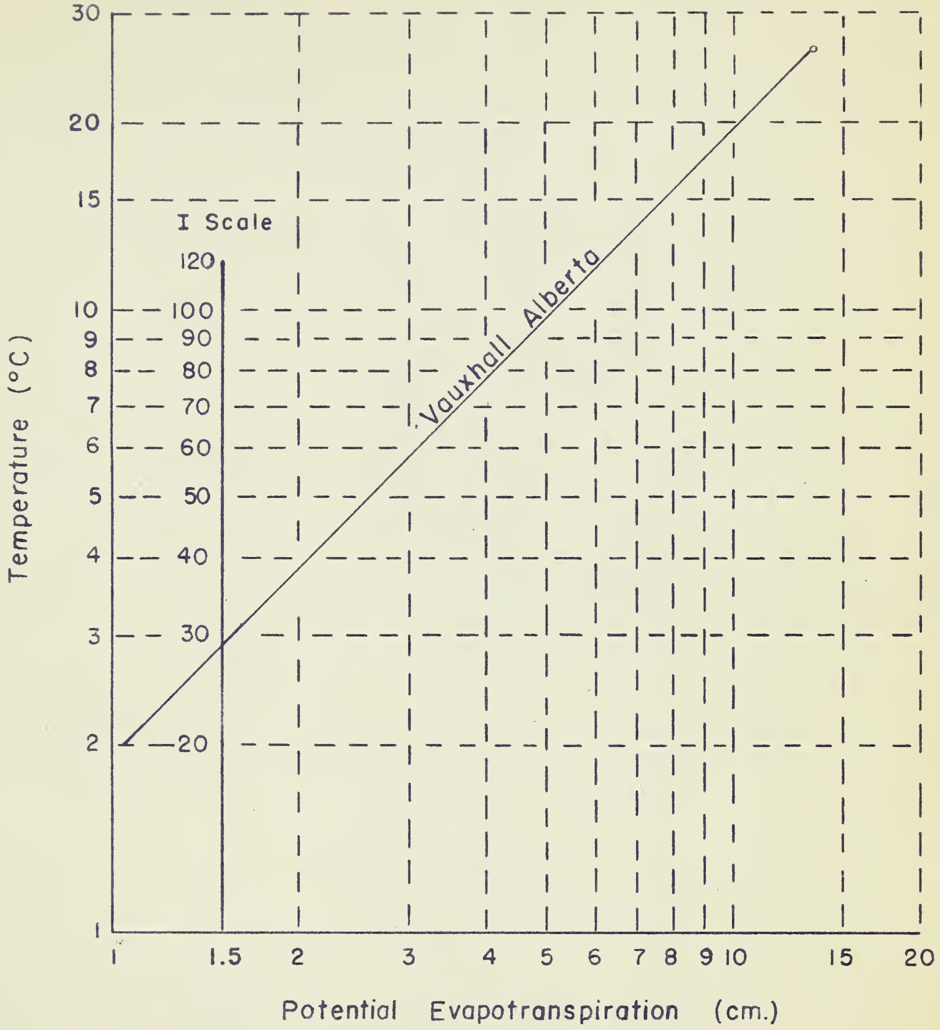
			Treatment W1 Allowable deficit = 5.2 in.			Treatment W2 Allowable deficit = 3.5 in.			Treatment W3 Allowable deficit = 1.9 in.		
Date	Latent Evapo. Transp.	Rain	Use = L.E.-T.x 0.6	Irr.	Deficit	Use = L.E.-T.x 0.8	Irr.	Deficit	Use = L.E.-T.x 1.0	Irr.	Deficit
Aug. 1	0.15		0.09		4.86	0.12		2.97	0.15		0.52
2	0.14		0.08		4.94	0.11		3.08	0.14		0.66
3	0.15		0.09		5.03	0.12		3.20	0.15		0.81
4	0.29		0.17		5.20	0.23		3.43	0.29		1.10
5	0.24	0.01	0.14	5.20	0.13	0.19		3.61	0.23		1.33
6	0.18	0.13	0.11		0.11	0.14	3.50	0.12	0.05		1.38
7	0.26		0.16		0.27	0.21		0.33	0.26		1.64
8	0.21		0.13		0.40	0.17		0.50	0.21		1.85

NOTE: All data are given in inches.

Table 3A. Monthly values of i corresponding to monthly mean temperatures. (Taken from Climatology, Vol. VIII,No.1.)

T^oC	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
0			.01	.01	.02	.03	.04	.05	.06	.07
1	.09	.10	.12	.13	.15	.16	.18	.20	.21	.23
2	.25	.27	.29	.31	.33	.35	.37	.39	.42	.44
3	.46	.48	.51	.53	.56	.58	.61	.63	.66	.69
4	.71	.74	.77	.80	.82	.85	.88	.91	.94	.97
5	1.00	1.03	1.06	1.09	1.12	1.16	1.19	1.22	1.25	1.29
6	1.32	1.35	1.39	1.42	1.45	1.49	1.52	1.56	1.59	1.63
7	1.66	1.70	1.74	1.77	1.81	1.85	1.89	1.92	1.96	2.00
8	2.04	2.08	2.12	2.15	2.19	2.23	2.27	2.31	2.35	2.39
9	2.44	2.48	2.52	2.56	2.60	2.64	2.69	2.73	2.77	2.81
10	2.86	2.90	2.94	2.99	3.03	3.08	3.12	3.16	3.21	3.25
11	3.30	3.34	3.39	3.44	3.48	3.53	3.58	3.62	3.67	3.72
12	3.76	3.81	3.86	3.91	3.96	4.00	4.05	4.10	4.15	4.20
13	4.25	4.30	4.35	4.40	4.45	4.50	4.55	4.60	4.65	4.70
14	4.75	4.81	4.86	4.91	4.96	5.01	5.07	5.12	5.17	5.22
15	5.28	5.33	5.38	5.44	5.49	5.55	5.60	5.65	5.71	5.76
16	5.82	5.87	5.93	5.98	6.04	6.10	6.15	6.21	6.26	6.32
17	6.38	6.44	6.49	6.55	6.61	6.66	6.72	6.78	6.84	6.90
18	6.95	7.01	7.07	7.13	7.19	7.25	7.31	7.37	7.43	7.49
19	7.55	7.61	7.67	7.73	7.79	7.85	7.91	7.97	8.03	8.10
20	8.16	8.22	8.28	8.34	8.41	8.47	8.53	8.59	8.66	8.72

Figure IA. Nomogram for determining potential evapotranspiration from mean temperature (as given in Publications in Climatology, Vol. VIII, No. I).



The point of convergence is at a mean temperature of 26.5°C. and at a potential evapotranspiration of 13.5 cm. The regression line for Vauxhall, 1957, is drawn from the point of convergence through the I value for Vauxhall for that year.

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